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EPA's New Emissions Trading Mechanism: A Laboratory Evaluation

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**ABSTRACT**

The EPA has designed a new call auction institution for trading allowances to emit sulfur dioxide. This paper reports twelve laboratory markets that investigate trader behavior in this new institution and evaluate its performance relative to the more commonly observed uniform price call market. We find that the uniform price call market (1) is more efficient, (2) induces more truthful revelation of underlying values and costs, (3) provides more accurate price information, and (4) is more responsive to and recovers more quickly from changes in underlying market conditions. All of these differences result from the intense strategic manipulation incentives of the EPA auction. Under the EPA auction rules both buyers and sellers misrepresent their true value of the emission permits, which biases market-clearing prices downwards. This suggests that the EPA auction will provide poor price signals to the evolving allowance market.

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## 1. INTRODUCTION

The centerpiece of the acid rain control program in the Clean Air Act Amendments of 1990 (“the Act”) is a system of tradable emission permits. Utilities must hold permits to emit sulfur dioxide, and the number of available permits will decline over time to reduce total emissions. Permit trading provides a more flexible means to achieve air quality objectives, in theory minimizing the overall cost of emission reductions. To ensure the availability of the permits (or, “allowances”) and to provide clear price signals to the evolving allowance market, the Act charges the Environmental Protection Agency (EPA) with the responsibility to conduct annual call auctions.<sup>1</sup> The Chicago Board of Trade conducted the first call auction for EPA in March 1993.

The research reported in this paper is motivated by the special features of the EPA call market. The Act states that “allowances shall be *sold on the basis of bid price*, starting with the highest-priced bid and continuing until all allowances for sale at such auction have been allocated” (emphasis added).<sup>2</sup> The EPA has interpreted this provision as requiring a discriminative auction with a unique feature: All sellers in this market receive the bid price of a specific buyer. Each successful buyer pays his or her own bid price, and sellers with the lowest asking prices receive the highest bids. Each bid and ask affects transaction prices, which creates strong incentives for traders to strategically manipulate the market. In contrast, call market institutions on financial exchanges have a uniform price rule that limits the traders’ abilities and incentives to manipulate price. Modern theory suggests that such features of the price determination process can have an impact on the actual prices.

This paper reports twelve laboratory markets that investigate trader behavior in this new institution and evaluate its performance relative to the more commonly observed uniform price call market. We find that the uniform price version of the call market (1) is more efficient, (2) induces

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<sup>1</sup>In the call market institution, potential buyers submit (sealed) bids specifying their maximum willingness to pay for the commodity, and potential sellers submit (sealed) offers (or “asks”) indicating the minimum price they are willing to accept for the commodity. [One can think of these bids and asks as “limit orders,” which may specify different prices for different units.] The market is “called” and trades are executed for all units with bids exceeding asks at a specific, pre-announced time using a previously specified rule for determining the price of each trade.

<sup>2</sup>*Clean Air Act Amendments of 1990* (Public Law 101-549), Sec. 416(d)(2).

more truthful revelation of underlying values and costs, (3) provides more accurate price information, and (4) is more responsive to and recovers more quickly from changes in underlying market conditions. All of these differences are due to the intense strategic manipulation incentives of the EPA auction. Under the EPA auction rules both buyers and sellers misrepresent their true value of the emission permits, so market-clearing prices are biased downwards. This suggests that the EPA-sponsored auction may provide poor price signals to the evolving allowance market, and may not provide accurate price information to firms that develop new technologies to control emissions.

Many different fields of economics such as auction theory, mechanism design theory, regulation, environmental economics, industrial organization, game theory and public economics have been joined to forge a case for the use of market mechanism to reduce the cost and increase the efficiency of environmental regulation. However, these areas were not consulted regarding the critical details of the EPA auction process. It is well known that the details of institutions can have a dramatic impact on market performance, but the EPA seems to have neglected the substance of the science that is available. If this highly visible market experiment fails because of problems of auction design, the repercussions could be significant. The weight of economic research has been effective in promoting a general movement toward auctioning various rights (such as the radio spectrum) which could be jeopardized if the EPA market fails to work. Therefore this paper can be seen as a step in identifying which specific rules have a positive or negative effect on market performance to guide policy makers that are interested in using a market approach to these other problems.

The paper is organized as follows. Section 2 summarizes the EPA auction and uniform price auction rules. Section 3 describes the experimental environment and treatment conditions. Section 4 discusses the experimental design, and Section 5 offers theoretical predictions for the different environments and trading institutions. Section 6 contains the experimental results and Section 7 concludes.

## 2. THE EPA AUCTION AND THE UNIFORM PRICE CALL AUCTION

The Acid Rain provisions of the Act primarily affect electric utilities, at least prior to 1999 (*i.e.*, during "Phase I"). A sulfur dioxide allowance authorizes the emission of up to one ton of sulfur dioxide, and beginning in 1995 the total annual emissions of each generating unit must be less than or equal to the number of permits held for that unit. Allowances may be transferred to and from any generating unit or any person. Consequently, each utility may meet its sulfur dioxide limitation in the most efficient means possible, either by choosing the most cost-effective emission control technology or buying emission permits from units with lower emission control costs. To maintain a cap on total emissions, new generation capacity must obtain allowances from existing allowance holders or through the EPA auctions and sales programs.

EPA will hold two separate call auctions during March of each year: A *spot* auction for permits allocated for the current year and an *advance* auction for permits effective in seven years. The Act allows any person holding permits to sell those permits in the auctions held by the EPA, but requires that the (reserve) permits in EPA's auction subaccount be sold before any private offerings. This subaccount contains allowances withheld from each utility's annual allowance allocation, and the EPA essentially forces these allowances into the auction with an asking price of zero. The number of permits in this subaccount in each of the two annual auctions varies from 150,000 to 250,000 between 1993 and 1999, but is set at 200,000 after 1999 (*i.e.*, in "Phase II"). These "mandatory" units are intended to ensure a minimum trading volume and represent 2.24 percent of the total permits allocated each year. The experiments do not include these mandatory units in order to focus on the incentives of the voluntary units offered for sale.<sup>3</sup>

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<sup>3</sup>Alternatively, we could interpret the buyers in the experiment as the utilities demanding additional permits after the EPA sells the first 200,000 mandatory units. ICF Resources (1989) estimated that cost savings from trading will fall in the range of \$1 billion per year, which would require total trading volume of several million units at current and projected permit prices in the \$150 to \$300 range. The number of units traded in the EPA auction will depend on the development of other private markets for allowances.

These auctions are two-sided—with both bids to buy and offers to sell—but the EPA interprets the Act to require successful buyers to pay their respective bids. The prices paid are determined as follows:<sup>4</sup>

All bids to the auctions will be ranked from highest to lowest on the basis of bid price. EPA will allocate and sell all the allowances in the auction subaccount on the basis of this ranking: when all such allowances are sold, EPA will match contributed allowances offered for sale with any remaining bids. Specifically, EPA proposes to match the offer to sell that stipulates the lowest minimum price with the highest remaining bid. This matching process will continue in ascending order of specified minimum price until all bids are awarded or allowances are consumed, or until EPA can no longer match bids with allowances because sellers have set their minimum price higher than any remaining bids.

In other words, the bids are arranged from highest to lowest, and the asks are arranged from lowest to highest. The lowest ask is matched with the highest bid and the trade occurs at the bid price; that is, units sold in this matching scheme receive the bid price of a specific buyer. *Lower* asking prices receive higher trading priority and thus lead to *higher* received prices, and all transacting bids and asks affect the (different) transaction prices.

In contrast to the EPA auction, specialists on the NYSE set the daily opening price for each share with a *uniform price* call auction. This institution is also common on exchanges worldwide for securities that have low trading volume. The auctioneer aggregates and arrays all bids and asks as revealed demand and supply schedules, and all trades occur at a uniform price where these schedules intersect. Only the bids and asks near the margin affect the (uniform) transaction price. The uniform price auction shares an important desirable feature with the EPA auction: low administrative costs because of their discrete nature compared to auction institutions that are open continuously. For this reason, it is the most logical alternative institution for comparison.

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<sup>4</sup>*Federal Register* [1991a], page 23746. The final rules published in the *Federal Register* [1991b] do not modify this proposal.

### 3. EXPERIMENTAL ENVIRONMENTS AND PROCEDURES

#### 3.1 Environments

A total of 12 sessions were conducted. Different sessions implement the two different call auction institutions. Eight sessions implemented the EPA auction rules described above. Four sessions implemented the uniform price auction commonly observed on financial markets.

Different sessions employed two different economic environments to capture two somewhat polar cases in which the auctions might need to function in the field. Since the theory of the EPA auction is not fully developed it is necessary to rely more heavily on the robustness of any properties observed. The only means available to this end is a proper choice of experimental environments. For this purpose we chose one environment in which the aggregate demands and supplies were constant for several periods (we called this the **constant aggregate case**) and a second environment in which the demands and supplies of each individual were drawn randomly each period (we call this the **random draws case**).

Each session was conducted for 24 market periods. In the constant aggregate case the aggregate demand and supply were constant for 16 periods and then were shifted once without warning. Figure 1 presents the aggregate demand and supply for this environment. Although the market aggregates were constant, the individual demands and supplies were rotated across subjects from period to period. In the random draws case, individual values were drawn from a uniform distribution (with replacement) each period. The distribution range remained constant for the first 16 periods and was shifted for the final 8 periods. This shift was announced. We imposed these sudden changes in the environment to study the possible evolution of the system to a new equilibrium.<sup>5</sup> Table 1 summarizes the parameters for the 12 sessions. An x in the experiment

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<sup>5</sup>For example, in the year 2000 the Act scales back the total permitted emissions to less than 9 million tons. Although traders know this emissions cap, its implication for permit values is uncertain. Traders will foresee some of the price implication through permit futures prices. We announced the shift in the random draws case because common knowledge of the distribution of possible values is required for any characterization of a Bayesian-Nash equilibrium. We did not announce the shift in the constant aggregate case because (1) subjects never receive value and cost information in constant parameter experiments and (2) we were interested in studying the adjustment path to a new, unknown (to subjects) equilibrium under the extreme equilibrium strategies of the EPA auction.



name denotes the experienced sessions. Inexperienced subjects had never before participated in a two-sided auction market experiment. Section 4 below discusses the experimental design.

### 3.2 Procedural Details

Each session employed eight students drawn from upper division economics classes at USC. The subjects were typically economics and business majors in their junior and senior years. The appendix contains instructions for the EPA auction sessions. Upon arriving at the laboratory, subjects were randomly assigned a buyer or seller role and a PC. Subjects remained in the same role throughout the session, and each had a trading capacity of four units per period. Buyers earned profits by purchasing units at prices below their “resale values” and sellers earned profits by selling units at prices above their “costs.” Note that unlike some previous laboratory research concerning emission permit trading (*e.g.*, Franciosi et al., 1993, and Cronshaw and Brown Kruse, 1992), the subjects do not acquire “permits” in order to produce. We employ a simplified, abstract trading commodity environment because our research interest is the alternative trading institutions.

At the beginning of each session, buyers (*resp.*, sellers) received a record sheet that indicated in cents the resale values (costs) for their four units for all 24 market periods. [Subjects also participated in an initial practice period to learn the operating procedures of the market software.] During the period, buyers (sellers) filled out electronic “bid sheets” indicating their maximum willingness-to-pay (minimum willingness-to-accept) for their four units. They could enter separate offers for each of their units or multiple-unit offers if they wished. The only requirements were that the total number of units bid for (or offered) was less than or equal to four and that every bid or ask price was greater than or equal to 1¢. Once subjects entered all bids and asks the experimenter called the market. Bids were arrayed from highest to lowest and asks from lowest to highest. Ties were broken randomly. A trade occurred between all bid-ask pairs in which the bid was greater than or equal to the ask. In the EPA auction sessions the different bids determined the different transaction prices, and in the uniform price sessions the midpoint of the market-clearing price interval determined the (common, uniform) price. The computer reported all the bids, asks, prices and trading volume to all the subjects. Therefore, similar to the EPA auction

implemented in the field, all bids, asks and prices (but of course not underlying true values and costs) were public information after the market call. Subjects entered the price information for their traded units on their record sheets and calculated their trading profits by hand. The experimenter carefully monitored these calculations. Subjects began with a \$5 starting capital credit balance to reduce the likelihood of bankruptcies from early losses (bankruptcies never occurred), and all trading profits for the 24 market periods were added to this starting balance. Sessions required 90 to 120 minutes to complete (including instructions), and subject earnings ranged from \$14 to \$50, with a mean of about \$33.

#### **4. EXPERIMENTAL DESIGN**

Table 2 summarizes the different treatment conditions and the location of the twelve sessions in different treatment cells. The design is obviously incomplete, but we chose to gather data in several conditions in order to compare the trading institutions in multiple environments. Behavior varied little across sessions within a treatment cell, so the small number of replications is unlikely to be misleading. Note also that the design is unbalanced. We only conducted four uniform price sessions because this institution has been studied extensively by Smith et al. (1982), Miller and Plott (1985), Van Boening (1991) and Friedman and Ostroy (1993). The uniform price institution is also relatively well-understood theoretically (see the following section). The main purpose of the four sessions reported here was to determine if nuisance parameters such as the subject pool, experimenter, instructions and laboratory market software changed the trader behavior and market performance. The results are broadly consistent with earlier laboratory research and theoretical models of this institution, so we felt comfortable focusing the limited resources on the unique EPA auction institution. Nevertheless, the four uniform price sessions provide comparison results for the EPA auction sessions that hold controllable nuisance parameters constant.

The experience treatment also requires discussion. Our main interest concerns trader and market behavior after subjects understand the rules of the EPA trading institution, and not the

learning process itself. The random draws case presents a more complex decision environment, so most random draws sessions employed experienced subjects. Additional experienced sessions in the constant aggregate case would be unlikely to add much insight, because behavior converged to and remained near the theoretical equilibrium after the first few inexperienced periods in all sessions. We did conduct one inexperienced random draws session to determine if the environment in which subjects receive experience has an important impact on behavior. This inexperienced session (EPARan5) generally had lower prices and efficiency than the comparable experienced random draws EPA auction sessions, so we believe subject experience is important. However, performance of this group of subjects in the experienced session EPARan6x is indistinguishable from the other experienced EPA auction sessions, which indicates that the source of experience is not important.

Finally, we wish to emphasize that although the experiment varies both experience and the constant versus random draws environments concurrently, we are *not* confounding the key treatment variable of interest (the trading institution). The data analysis for the institutional comparison only compares observations from the different auction institutions in identical experience and value draw conditions. The results identify similar institutional behavior and performance differences for (1) inexperienced subjects in the constant aggregate environment, and (2) experienced subjects in the random draws environment. The institutional differences we identify are stronger because they are present in different environment and experience settings. Both our results and our theoretical understanding make it highly unlikely that the experienced constant aggregate or the inexperienced random draw conditions hold anything interesting for study.

## 5. MODELS

A difficulty exists with applying general models from auction theory. The EPA auction is so complicated that a general game-theoretic solution to the natural auction model is unknown to us. In view of this problem we chose a setting in the constant aggregate case in which a Nash

equilibrium exists to the EPA auction. The existence results from a strategic choice of parameters. However, the natural model to apply to the uniform price auction becomes complicated because of the multiple units. For convenience of analysis we have chosen to assume that traders enter separate bids and asks for each unit. Of course that assumption can be evaluated using the data. The random draws case presents even more modeling problems that will be discussed below. The experimental design and the data analysis were developed in full realization of the difficulties caused by the lack of fully developed models, which of course is a frequent problem in economics.

### 5.1 EPA Auction in Constant Aggregate Case

Subjects in the constant aggregate sessions knew only their own values or costs, but over time they learned about the overall market conditions through bids, asks, prices and trading volume. In particular, in the constant aggregate case subjects observe the evolution of market-clearing prices, and these prices appear to converge to the lower bound of the competitive equilibrium price interval ( $P_{CE}$ ).<sup>6</sup> Following Smith et al. (1982) and Miller and Plott (1985) we describe a static Nash equilibrium bidding model under certainty and assume that each trader knows  $P_{CE}$ .<sup>7</sup> With the demand and supply conditions shown in Figure 1 it is easy to identify Nash equilibrium strategies, although these strategies are not unique. Notice that these curves have the very special feature that at  $P_{CE}=220$  the supply intersects the demand but there are extra, “hangover” demand units. These extra-marginal units are important for the unique features of the Nash equilibrium.<sup>8</sup>

First consider the problem facing a buyer with reservation value  $v$ . Bids above  $v$  are never optimal under the EPA rules because buyers must pay their bid price if their bid is accepted. Bids at or below 220 can be beat or tied by extra-marginal buyers with  $v=220$ . All bids above  $220+1\text{¢}$  will be accepted, so the buyer with  $v>220$  has an incentive to bid exactly  $b=220+1\text{¢}$  (1¢ is the smallest possible increment). The Nash equilibrium requires that if  $v=220$  then  $b=v$  even though

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<sup>6</sup>Alternatively, we could develop a dynamic model similar to the argument presented below replacing  $P_{CE}$  with the market-clearing price in the previous period,  $P_{t-1}$ .

<sup>7</sup>Friedman and Ostroy (1993) provide a theoretical justification for this “as if” complete information approach based on Dubey (1982) and others.

<sup>8</sup>The discussion that follows uses the parameters employed in periods 1-16 of the sessions.

these bids are not accepted. For all  $v < 220$  the buyer is indifferent between any bid (less than  $v$ ) because her bid is not accepted.

Next consider the problem facing a seller with cost  $c$ . Under the EPA rules the sellers with the lowest ask prices receive the highest bids. If  $c \leq 220$  and if 10 buyers bid  $220 + 1\text{¢}$  then this seller is indifferent between any ask between  $220 + 1\text{¢}$  and the lower bound  $1\text{¢}$ , because (in equilibrium) this ask will be accepted and will receive a bid price of  $220 + 1\text{¢}$ . However, if *any* dispersion exists in bid prices above 220 then this seller strictly prefers an ask on the lower bound of  $1\text{¢}$  because this increases the expected price received. Therefore, an ask of  $1\text{¢}$  is (perhaps weakly) optimal for sellers with  $c \leq 220$ . If  $c > 220$  then the seller is indifferent between any ask (greater than  $220 + 1\text{¢}$ ) because all bids are less than or equal to  $220 + 1\text{¢}$  and therefore the ask will not be accepted.

To summarize, our candidate equilibrium bid and ask strategies [respectively  $b(v)$  and  $a(c)$ ] in the constant aggregate case are the following:

$$(1) \quad b(v) = \begin{cases} 220 + 1\text{¢} & \text{for } v > 220 \\ b = v & \text{for } v = 220 \\ \text{any } b < 220 & \text{for } v < 220 \end{cases}$$

$$(2) \quad a(c) = \begin{cases} 1\text{¢} & \text{for } c \leq 220 \\ \text{any } a > 220 + 1\text{¢} & \text{for } c > 220 \end{cases}$$

Figure 2 illustrates these strategies for the constant aggregate parameters of periods 1-16. We refer to the bid strategy as the “elbow” strategy (a term coined by Miller and Plott (1985)) and the ask strategy as the “jump” strategy. It is straightforward to verify that these strategies constitute a (non-unique) Nash equilibrium. Intuitively, buyers with values above 220 decrease profit for any  $b \neq 220 + 1\text{¢}$ , and buyers with values below 220 can only lose money with any bid above 220. Sellers with costs less than or equal to 220 are indifferent between any ask less than or equal to  $220 + 1\text{¢}$  that allows them to trade, but they strictly prefer to ask  $1\text{¢}$  if there exists any dispersion in accepted bid prices. Sellers with costs above 220 lose money with any ask at or below  $220 + 1\text{¢}$ . Because sellers ask  $1\text{¢}$ , it might appear that buyers could exploit sellers by entering very low bids; however, the extra-marginal buyers discipline the infra-marginal buyers to bid no less than  $220 + 1\text{¢}$ .

Note that in spite of their substantial value and cost misrepresentation, these strategies imply high trading efficiency.

### 5.2 Uniform Price Auction in Constant Aggregate Case

Smith et al. (1982) discusses the theoretical properties of the uniform price auction with constant values. Traders in this institution also have an incentive to misrepresent their values and costs. Lower bids (higher asks) imply lower (higher) prices, so buyers (sellers) never wish to bid above value (ask below cost). The extra-marginal units, however, discipline the amount of profitable misrepresentation because they can displace profitable infra-marginal units. For example, in the parameters for periods 1-16 of the constant aggregate sessions infra-marginal buyers must bid no less than 220 to avoid being (profitably) displaced by one of the extra-marginal units. Similarly, infra-marginal sellers must ask no more than 240. The amount of misrepresentation can be significant for the high value and low cost units, but this misrepresentation is unlikely to affect the (uniform) price. The units near the margin that determine price should “almost” fully reveal values and costs to avoid being excluded from profitable trades. Any efficiency losses should be small in this institution because of the low profitability of the marginal units that may be excluded from trade.

### 5.3 EPA Auction in Random Draws Case

The random draws case provides an environment that can, in theory, be formally modeled as a Bayesian game of incomplete information following the approach pioneered by Vickrey (1961) for one-sided auctions. Each trader knows her own value or cost draw and the probability distribution governing the other traders’ values and costs. Given these distributions and her beliefs regarding the bid and ask strategies employed by other traders, this trader can calculate the expected profit of any bid or ask. Each trader maximizes expected profit given these (consistent) beliefs regarding rival behavior, and if the strategies are mutual best-responses then they constitute a Bayesian-Nash equilibrium.

This approach is straightforward for one-sided auctions (*i.e.*, in which buyers submit bids and the seller is non-strategic), but it becomes considerably more complicated if both buyers and

sellers are present as in the call auctions studied here. Each bid and ask must be a best response to both the buyer and seller strategies. As described in the next subsection, Rustichini, Satterthwaite and Williams (1994) have successfully characterized a set of Bayesian-Nash equilibria for the two-sided uniform price auction by cleverly exploiting the fact that traders need only consider marginal probabilities in this institution. These equilibria are not solved in closed form but are characterized by a system of non-linear differential equations. The EPA auction is more complex theoretically than the uniform price auction because traders' objective functions depend on the entire distribution of other traders' bids and asks. Cason (1993) provides one approach to overcome this problem for the EPA auction by relying on some simplifying assumptions.

Because of these difficulties, we have not characterized an equilibrium for the EPA auction. However, we believe that we have the correct intuition for a theoretical equilibrium based on principles from auction theory. First consider the buyers. Since buyers pay their bid price, they are facing a strategic environment similar to the one-sided multiple-unit discriminative auction (without strategic sellers) studied theoretically and tested experimentally in Cox, Smith and Walker (1984). The two-sided EPA auction institution introduces two complications. First, buyers are facing strategic sellers that can submit positive asking prices rather than the zero seller reservation prices assumed in the one-sided institution. However, most units that trade have 1¢ asking prices so this complication is minor. Second, the number of units offered by sellers is endogenous in the two-sided EPA auction. For our parameters with 16 cost draws, typically 7 or 8 units trade each period. Although a fully rational theoretical model must account for the expected number of offered units through beliefs about seller ask strategies, our analysis of the data (see Section 6.3 below) suggests that this complication is also of minor importance empirically. Buyers bid as if they expect sellers to offer 7 or 8 units.

Under assumptions of a uniform distribution for values and risk neutrality, the (one-unit) discriminative auction equilibrium bid function is a linear function of value with slope  $(N-1)/N$ . [ $N$  is the number of competing buyer units.] Cox, Smith and Walker (1984) show that with multiple units for sale (with a known asking price of 0) the equilibrium bid function is concave and implies

lower bids as the number of offered units ( $Q$ ) increase. With 16 value draws from the uniform distribution over  $[0, 250]$ , the risk neutral bid function has an asymptote of about 125 with  $Q=8$  units offered. With  $Q=7$  units offered, the bid function has an asymptote of about 145. The results section (Figure 11) displays these bid functions, which have an “elbow” shape similar to the constant aggregate case.

Next consider the sellers. The uniform distribution of values is filtered through the buyer's bid function to generate the distribution of bids. Successful sellers in this environment receive the bid price of a specific buyer drawn from this distribution. If values are drawn from the range  $[0, 250]$  and buyers employ the multiple unit discriminative auction bid strategy based on  $Q=7$  units offered, the unconditional expected value of a single bid draw from this distribution is 94. However, accepted bids are usually in the upper half of the bid distribution because only the top 7 or 8 are typically accepted. This complication is handled with order statistics. Furthermore, if a seller asks  $a$  for a unit then  $a$  truncates the distribution of possible bid prices received conditional on acceptance. For these two reasons the expected bid price received conditional on  $a$  and acceptance (denoted  $\bar{b}(a)$ ) is considerably greater than 94. It can be shown that if values are drawn from  $[0, 250]$  and buyers bid as if they expect 8 (or 7) units to be offered then the expected price received for an ask of 1¢ is approximately  $\bar{b}(1)=117$  (or 131). Therefore, the optimal ask for risk neutral sellers with low cost draws below some cutoff  $c^*$  is the corner solution of 1¢. The cutoff  $c^*$  is somewhere in the range between 117 and 131.

The optimal ask strategy for sellers with higher cost draws above  $c^*$  is less clear. We believe that it is never optimal to ask above cost in the EPA auction because doing so can only eliminate potentially profitable trades. We conjecture that the equilibrium exists in pure strategies and that there exists an optimal  $a(c) \leq c$  for all  $c > c^*$  that increases monotonically in  $c$ . We also conjecture that this ask strategy is discontinuous at  $c^*$ , which implies a “jump” strategy similar to the constant aggregate case.



#### 5.4 Uniform Price Auction in Random Draws Case

Fortunately, we need not rely on intuition and informal arguments for the uniform price auction with random draws. Rustichini, Satterthwaite and Williams (1994) have numerically characterized a set of differentiable equilibrium bid and ask strategies for this institution. [In Rustichini et al.'s terminology, we employ rules with  $k=0.5$ , setting price at the midpoint of the market-clearing price interval.] Their results show that *precisely because only the marginal traders affect price* under the uniform price rules, traders have an incentive to “almost” fully reveal their true valuations in their bids and asks. We can make the term “almost” precise based on the number of units involved in the auction, because value and cost misrepresentation decrease with increased volume. With the 16 value draws and 16 cost draws in the present environment, risk neutral buyers bid approximately 97 percent of their value and risk neutral sellers ask approximately 103 percent of their cost. Figures 14 and 15 in the results section display these equilibrium bid and ask functions. This truthful revelation implies that the market exploits nearly all available gains from exchange.

#### 5.5 Models Summary

Table 3 summarizes the predicted behavior based on our understanding of the theoretical properties of these institutions. Predicted behavior is similar in both environments. In the EPA auction, theoretical considerations suggest an elbow shape for the buyers' bids and a discontinuous jump in the sellers' asks. Predicted price in the constant aggregate environment under EPA auction rules is at the bottom of the competitive equilibrium price interval ( $P=220$  in periods 1-16,  $P=280$  in periods 17-24) because the extra-marginal buyer values set the lower bound on acceptable bids. The theory predicts that market efficiency will be 100 percent in the constant aggregate case. In the random draws environment the EPA auction price may be less sensitive to underlying value and cost variation because the elbow and jump strategies may cause most of the accepted bids to lie in the 110-140 range regardless of the actual draws. In the uniform price auction, theory predicts that buyers and sellers reveal values and costs at the margin, implying prices in the competitive price interval and near 100 percent efficiency.

## 6. RESULTS

We present the results in three subsections. The first subsection examines the overall market-level measures of behavior relative to the theoretical models of the two institutions. The second subsection compares behavior and performance of the two institutions. The patterns of market-level data revealed in the first subsection generally support the theoretical models. The final subsection contains a more detailed analysis of buyer and seller trading strategies.

### 6.1 Market Level Data

Figures 3 through 6 contain time series data from four representative sessions. Figures 3(a) through 3(c) contain all of the bids and asks for each of the 24 periods of session EPACon2. This session employed the EPA auction rules and constant market demand and supply across periods, although one supply and demand shift occurred between periods 16 and 17. On these figures circles represent bids and squares represent asks. Solid black (filled) circles and squares indicate accepted bids and asks that resulted in transactions. White (unfilled) circles represent bids that we not accepted because they were matched with higher (unfilled square) asks. The dotted lines indicate the true redemption values and costs, ordered from highest to lowest and lowest to highest, respectively, and not in the order of the associated bids and asks. The solid horizontal line indicates the midpoint of the competitive equilibrium (CE) price interval. Figures 4(a) through 4(c) contain all of the bids and asks for session EPARan2x. In this session with EPA auction rules, subjects were experienced and the redemption values and costs were drawn randomly from the uniform distributions indicated in the title of the figures. Figures 5(a) through 5(c) present data from UNICon1, which is a constant aggregate, uniform price session. Figures 6(a) through 6(c) present data from UNIRan2x, which is a random draws, uniform price session.

A glance at the figures suggests several of the major results. The data from all experiments have the qualitative properties of the theory discussed in the previous section. The first three results below attempt to make these impressions precise for the EPA auction. Results 4 and 5 address the uniform price auction, and essentially report that the data are consistent with the properties of the uniform price auction discussed above and results reported elsewhere.

Together Results 1 and 2 state that the trader behavior substantially confirms the Nash equilibrium predictions for the constant aggregate sessions. Furthermore, the elbow and jump models suggest properties of the data that are also observed in the random draws sessions. Figure 3(a) illustrates that sellers learn quickly in the inexperienced constant aggregate sessions to ask 1¢ in order to receive the highest bid prices. Sellers also employ this strategy immediately in the experienced random draws sessions; see Figure 4(a). Buyers learn more slowly that bids near the lower bound of the CE price interval are high enough to trade. Note that some dispersion accepted bids remains even at the end of the sessions, which makes low-cost sellers' 1¢ asks a strict best-response.

**RESULT 1:** In the EPA auctions the bid data have the qualitative properties of the elbow model, and the movement of bids over time is in the direction of the elbow model.

Support:<sup>9</sup> The qualitative properties are clear from Figures 3 and 4, which are representative of all 8 EPA auction sessions. To demonstrate the movement of bids over time towards the elbow model, we calculate the average absolute deviation of buyer bids from the predicted Nash equilibrium elbow defined in equation (1) for the constant aggregate sessions. [For this calculation we employ a Nash prediction that extra-marginal bids equal values, although these bids are only bound by the CE lower bound in equilibrium.] This mean absolute deviation is 16.1¢ in the first 8 periods of the sessions, but falls to 9.5¢ in the second 8 periods of the sessions [T-statistic for difference=5.02].<sup>10</sup> The parameter shift between periods 16 and 17, however, increases the mean absolute deviation from the new Nash prediction to 15.3¢ for the final 8 periods. [This mean deviation falls only to 14.5¢ for the final 4 periods.]

In the random draws sessions, we calculate the average absolute deviation of bids from the Nash elbow approximation suggested by the multiple-unit discriminative auction bid function with  $Q=7$  units offered, as discussed above in section 5.3. The mean absolute deviation falls from

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<sup>9</sup>As discussed in Section 4, in reporting all quantitative results we pool across the four experienced EPA auction, random draws sessions. We exclude the single inexperienced session EPARan5 in order to not confound the primary institutional treatment with experience and to provide a fair comparison across institutions.

<sup>10</sup>Throughout this section we report T-statistics to aid in the reader's interpretation of the results. However, the standard significance levels for the T-statistics are not valid because the observations are not independent across periods within a session.

13.3¢ in the initial 8 periods to 10.4¢ in the second 8 periods of the sessions [T-statistic=3.67]. Like the parameter shift in the constant aggregate sessions, the distribution shift between periods 16 and 17 increases the mean absolute deviation from the new elbow prediction to 13.8¢ for the final 8 periods. [This mean deviation falls only to 13.7¢ for the final 4 periods.] Across both environments, it appears that bids move towards the elbow prediction under stable conditions; however, after parameter changes such as those following period 16, buyers require time to adjust to the new elbow equilibrium. This adjustment period apparently exceeds 8 periods.<sup>•</sup>

**RESULT 2:** In the EPA auctions the ask data have the qualitative properties of the jump model, and the movement of asks over time is in the direction of the jump model.

Support: The qualitative properties are also clear from Figures 3 and 4. We again calculate the average absolute deviation of seller asks from the predicted Nash equilibrium, in this case from the jump model defined in equation (2) for the constant aggregate sessions. [For this calculation we employ a Nash prediction that extra-marginal asks equal costs, although these asks are only bound by the CE lower bound in equilibrium.] This mean absolute deviation falls from 67.7¢ in the first 8 periods to 45.9¢ in the second 8 periods [T-statistic=3.09]. The parameter shift between periods 16 and 17 increases the mean absolute deviation from the new Nash prediction to 107.9¢ for the final 8 periods, but two extreme asks in the final period (808 and 9999) entirely explain this increase. Dropping period 24, the mean absolute deviation for the periods 17-23 is 46.6¢.

In the random draws sessions, we calculate the average absolute deviation of asks from the following jump approximation:

$$(3) \quad a(c) = \begin{cases} 1¢ & \text{for } c \leq \bar{c} / 2 \\ c & \text{for } c > \bar{c} / 2 \end{cases}$$

where  $\bar{c}$  is the highest possible cost draw—250 in periods 1-16 and 300 in periods 17-24. The mean absolute deviation from this jump model falls from 25.3¢ in the initial 8 periods to 22.7¢ in the second 8 periods of the sessions [T-statistic=0.70]. The distribution shift between periods 16 and 17 increases the mean absolute deviation from the new jump prediction to 31.2¢ for the final 8 periods.<sup>11</sup> Like bids and the elbow model, it appears that asks move towards the jump prediction

<sup>11</sup>This mean deviation is slightly higher in the final 4 periods (32¢) because of a substantial mean absolute deviation of 68¢ in the final period. Dropping period 24, the mean absolute deviation for the periods 17-23 is 26.4¢.

under stable conditions (especially in the constant aggregate case) but can diverge after parameter changes.\*

The first two results suggest that the bids and asks are qualitatively consistent with our theoretical understanding of the incentives in the EPA auction institution, but they say nothing about the prices that result from the auction. Define the market clearing price as the final transaction price at the margin when the auctioneer intersects the revealed supply and demand arrays. This is the most important price signal from the market because it reveals the marginal terms of trade buyers and sellers must meet in order to be included in the market transactions. It is also a widely distributed market summary statistic; for example, the *Energy Daily* and the *Wall Street Journal* mention the range of transaction prices (\$122 to \$450) in the first and second sentences, respectively, of their articles reporting the initial EPA auction results. Neither article even mentions the average price paid (see Lobsenz, 1993, and Taylor, 1993). The next result states that the market clearing prices in the EPA auction are below the competitive equilibrium.

**RESULT 3:** In the EPA auctions the market clearing prices are below the competitive equilibrium in both the constant aggregate and random draws environments, and average prices are below the competitive equilibrium midpoint in the constant aggregate environment. These qualitative features are consistent with theory.

**Support:** Across all 3 constant aggregate sessions, market clearing prices are below the CE price midpoint in all of the 72 periods. These prices are within the CE price interval in only 19 of the 72 periods (26 percent). In the 4 random draws sessions, market clearing prices are below the CE prices in 79 of the 96 periods (82 percent). Average market clearing prices (by period) are below the CE price interval midpoint in all 24 periods in the constant aggregate sessions, and in 23 of the 24 periods in the random draws sessions (see Figures 9 and 10 below). The market clearing price is always the lowest transaction price each period, so average transaction price always exceeds the market clearing price. Nevertheless, average prices are below the CE price interval midpoint in all 24 periods in the constant aggregate sessions. In the random draws sessions, average prices are below the CE price interval midpoint in 9 of the 24 periods.

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The divergent behavior in the final period in both environments is probably due to end of experiment effects, because subjects knew the session would last exactly 24 periods.

These price results for the EPA auction are entirely consistent with the theoretical model. In the constant aggregate case the model predicts that average and market clearing prices should be near the lower bound of the CE price interval (and below the CE interval midpoint), and the data support this prediction. In the random draws case the model predicts that many asks will be 1¢ and many bids will be in the range near the midpoint of the value distribution. This implies that most transaction prices will be near the midpoint of the value distribution, so that average prices exceed the CE price only when the CE price happens to be below the midpoint of the value distribution. The data also support this implication of the model. The CE price is below the midpoint of the value distribution in 11 of the 15 periods in which the average price exceeds the CE price, but the CE price is below the midpoint of the value distribution in 0 of the 9 periods in which the CE price exceeds the average price. In other words, average prices under the EPA auction rules are less responsive to changes in underlying market conditions than implied by the changing CE price.<sup>12</sup>

The next two results (4 and 5) concern the uniform price auctions and are standard to the literature. They demonstrate that the uniform price auction tends to induce value and cost revelation at the margin. This tendency increases over time and with experience. As a consequence the prices in the uniform price auction are close to the competitive equilibrium prices.

**RESULT 4:** In the uniform price auctions the bids and asks for units near the margin tend to reveal the true values and costs of those units, and this revelation increases over time.

**Support:** Review Figures 5 and 6 for qualitative support for this conclusion. Buyers tend to bid above and below value and sellers tend to ask above and below cost. At the margin, however, sellers and buyers generally reveal costs and values. To support this conclusion quantitatively, first define the marginal units as those that are immediately to the left and to the right of the true value and cost array intersection. The bids and asks for these units are the most likely to affect the (uniform) transaction price and should most closely reveal true values and costs. The

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<sup>12</sup>Another way to demonstrate this point is to compare the CE price variance and average price variance across periods in the random draws case. The variance of theoretical CE prices is 540, while the variance of actual average prices in the EPA auctions is only 96. The variance of average prices in the uniform price auction is 439.

statistics we employ to document this result are the mean absolute deviations of bids from value and asks from cost for these marginal units. In the constant aggregate sessions, the mean absolute (marginal) bid deviations are 36.0¢, 22.3¢ and 22.4¢ in the first 8, second 8 and final 8 periods, respectively [T-statistic for the first 8-second 8 comparison=1.97; for the second 8-final 8 comparison=0.02]. Also in the constant aggregate sessions, the mean absolute (marginal) ask deviations are 23.1¢, 10.6¢ and 43.6¢ in the first 8, second 8 and final 8 periods, respectively [T-statistics=2.41, 1.81]. [In the final 4 periods the mean absolute ask deviation falls to 19.5¢.] In the random draws sessions, the mean absolute (marginal) bid deviations are 27.6¢, 20.8¢ and 17.0¢ in the first 8, second 8 and final 8 periods, respectively [T-statistics=1.10, 0.70]. Also in the random draws sessions, the mean absolute (marginal) ask deviations are 9.0¢, 7.7¢ and 6.2¢ in the first 8, second 8 and final 8 periods, respectively [T-statistics=0.38, 0.49]. As documented below in Result 8, this level of value and cost revelation is generally much greater than the level of revelation in the EPA auction.<sup>13</sup>

**RESULT 5:** In the uniform price auction, prices are near the competitive equilibrium and move closer to the competitive equilibrium over time.

Support: Across all constant aggregate sessions, prices are within the CE price interval in 75 percent of the periods. In the more challenging random draws sessions, observed prices track CE prices fairly well. We employ the mean absolute price deviation from the CE as the statistic to document this price result. In the constant aggregate sessions, the mean absolute deviations of actual transaction prices from the CE price interval midpoints were 11.3¢, 7.5¢ and 9.1¢ in the first 8, second 8 and final 8 periods, respectively [T-statistics=2.56, 1.09]. In the random draws sessions, these deviations were 9.0¢, 7.6¢ and 9.3¢ in the first 8, second 8 and final 8 periods, respectively [T-statistics=0.53, 0.59]. Similar the bid and ask behavior, prices do not immediately follow the change in the CE after the value and cost distributions shift between periods 16 and 17.

The substance of Results 1 through 5 is that the Nash equilibrium model for the constant aggregate case is a useful model for characterizing properties of both the constant aggregate and the

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<sup>13</sup>It is interesting that the asks generally revealed costs more completely than the bids revealed values. The Nash model of bid and ask behavior does not predict this result because it treats buyer and sellers symmetrically.

random draw sessions. We therefore have confidence in the elbow and jump model for the EPA auction in spite of our inability to characterize it formally for the random draw environment. All 8 EPA auction sessions generate the same qualitative bid and ask patterns, so this model has strong empirical support. Furthermore, behavior in the uniform price auctions was consistent with previous laboratory studies and existing theoretical models. The next subsection turns to a direct performance comparison of the two auctions, and subsection 6.3 returns to additional analyses of bid and ask behavior.

## 6.2 Institutional Comparisons

The analyses of this section involve simple comparisons of the two auction institutions that are independent of theory. In this subsection we present evidence that the uniform price rules outperform the EPA auction rules. The first comparison concerns the overall market efficiency of the two institutions, and demonstrates that the uniform price auction dominates the EPA auction.

**RESULT 6** Efficiency of the uniform price auction is greater than the efficiency of the EPA auction, except in the initial periods in the constant aggregate environment.

Support: Figures 7 and 8 display average efficiency by period in the constant aggregate and random draws environments, respectively. In the constant aggregate environment (Figure 7), the uniform price auction has lower efficiency initially, but efficiency improves steadily across periods. In contrast, the EPA auction efficiency is higher initially but shows little improvement over time. The EPA auction has higher average efficiency in the first 8 periods, but the uniform price auction has higher average efficiency in most of the final 16 periods. In the random draws environment (Figure 8), the uniform price auction consistently has high efficiency while the EPA auction has serious performance deficiencies in many periods. The uniform price auction has higher average efficiency in 19 of the 24 periods in this environment. Overall, in the inexperienced constant aggregate environment, the EPA auction efficiency averages 89.7 percent compared to the uniform price average efficiency of 90.9 percent [T-statistic=0.74]. The differences are more substantial in the experienced random draws environment; in this case, the EPA auction efficiency averages 91.5 percent, while the uniform price average efficiency is 96.2 percent [T-statistic=4.46].•



Not only is the efficiency of the EPA auction lower than the uniform price auction, but the EPA auction prices are lower as well.

**RESULT 7:** Prices of the uniform price auction are closer to the competitive equilibrium prices and are higher than the market clearing prices of the EPA auction.

**Support:** Figures 9 and 10 display average market clearing prices by period in the constant aggregate and random draws environments, respectively. In the constant aggregate environment (Figure 9), the uniform price auction provides average prices that almost perfectly correspond to the midpoint of the CE price interval. Average prices are always within the CE price interval (with one exception in period 18) and average prices are nearly always within a couple of cents of the CE price interval midpoint. By comparison, the EPA auction average market clearing prices are always below the uniform price auction prices and always below the midpoint of the CE price interval. However, they do finally converge from below to the lower end of this interval (220) by period 14, as implied by the elbow and jump model. In the random draws environment (Figure 10), average market clearing prices in the EPA auction sessions are below the CE price interval midpoint in 23 out of 24 periods. The EPA auction average clearing prices fall below the lower bound of the CE price interval (not shown) in 20 out of 24 periods. Average prices are closer to the CE price interval in the uniform price institution in 17 of the 24 periods, and average prices are lower in the EPA auction sessions than the uniform price auction sessions in 22 out of 24 periods. The mean absolute deviation of market clearing price from the CE price interval midpoint is 20.5 cents in the EPA auction and is 8.6 cents in the uniform price auction [T-statistic=6.19].•

The above result indicates that the differences in market behavior are the result of rather strong motivational tendencies that exist in these institutions. The EPA auction creates incentives for both the buyers and the sellers to under-reveal their true values and costs. In contrast, buyers and sellers in the uniform price auction are motivated toward truthful revelation. Given these tendencies it is perhaps not surprising that prices in the EPA auction are low relative to both the CE and the uniform price auction. The theoretical implication of the elbow and jump model for the EPA auction implies prices at the lower bound of the CE price interval in the constant aggregate

environment; however, average market clearing prices are nearly always below this level. The next result compares the value and cost revelation implied by the bids and asks for the two institutions.

**RESULT 8:** Value and cost revelation are greater under the uniform price auction than under the EPA auction.

Support: Similar to the analysis supporting Result 4, we compute the mean absolute deviations from truthful revelation, where bid=value and ask=cost define truthful revelation. However, in this institutional comparison we include all bids and asks (not just those for marginal units) and compare institutions by period. In the constant aggregate environment, the mean absolute deviation from truthful revelation is smaller in the uniform price auction for all 24 periods for asks and for 20 out of 24 periods for bids. [The mean bid deviation from revelation is smaller in all 16 final periods.] In the random draws environment, the mean absolute deviation from truthful revelation is smaller in the uniform price auction for all 24 periods for both bids and asks.\*

Although the choice of the EPA auction rules is puzzling, it may be due to faulty intuition about auction incentives (the conclusion examines this issue in more detail). There is evidence from House committee hearings on the Act that Congress chose discriminative price rules to increase the returns to the initial allowance holders, mainly large investor-owned electric utilities.<sup>14</sup> The next result compares the seller profits in the two institutions to determine if this objective is realized in the laboratory data.

**RESULT 9:** Seller profits are no higher in the EPA auction than the uniform price auction, and seller profits are lower in the EPA auction in the constant aggregate environment.

Support: In the constant aggregate environment sellers obtain 44.2 percent of the trading surplus in the EPA auction, compared to a 49.7 percent seller share in the uniform price auction [T-statistic=3.34]. Sellers as a group earn \$95.52 under EPA auction rules, and earn \$108.54 under uniform price rules on average in this environment. Seller earnings are similar for the two trading institutions in the random draws environment. Sellers earn a 52.8 percent share under EPA rules, and a 51.2 percent share under uniform price rules [T-statistic=0.83]. Although their share is slightly smaller under uniform price rules, sellers earn slightly more in the uniform price sessions

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<sup>14</sup>Personal communication with Thomas Black of the General Accounting Office.

because of the higher efficiency of the uniform price institution in the random draws environment (Result 6): Sellers as a group earn an average of \$120.11 in the uniform price sessions, compared to \$119.49 for the EPA-rule sessions. •

These results demonstrate that the discriminative pricing feature of the EPA auction rules fails to raise seller returns relative to uniform price rules, and these rules actually lower seller returns in the constant aggregate environment. This arises from the incentives to misrepresent values and costs in this setting.

The strategic behavior induced by the auction rules can cause systems to be unresponsive to underlying economic conditions. The next result summarizes the consequences when conditions change unexpectedly. How will the system respond if the economic parameters change without warning? Will the system respond to facilitate the gains from exchange that might exist under the new circumstances? Will prices reflect the new economic conditions? The constant aggregate sessions included the unannounced parameter shift between periods 16 and 17 to answer these questions.

**RESULT 10:** The efficiency level immediately following an unexpected parameter change is higher in the uniform price auction than the EPA auction, and prices respond more rapidly in the uniform price auction.

Support: Consider again the efficiency and price comparison Figures 7 and 9 for the constant aggregate environment. After the unannounced parameter shift between periods 16 and 17 efficiency plummets in the EPA auction sessions and takes a couple of periods to recover. The market clearing price also reacts slowly to this parameter shift in the EPA auction sessions. In the uniform price sessions, efficiency falls only slightly and prices adjust much more quickly. Prices converge to the CE price midpoint in the uniform price auction within three periods, while market clearing prices never reach even the lower bound of the CE price interval in the EPA auction sessions during the 8 periods after the shift. •

This unresponsiveness to changes in underlying conditions is a major difference between the institutions. The greater value and cost revelation of the uniform price auction (Result 8) makes its price changes more sensitive to changes in these fundamentals. In the EPA auction, traders

need to learn about the CE to extract full surplus and generate prices at the lower bound of the CE price interval; therefore, this institution does not respond quickly when underlying shifts generate uncertainty.

The substance of the last five institutional comparison results is that the uniform price auction has higher efficiency than the EPA auction; the uniform price auction generates higher clearing prices that are closer to the competitive levels; sellers obtain no less and sometimes obtain more exchange surplus in the uniform price auction; and the uniform price auction prices convey more accurate information and are more responsive to changing conditions than the EPA auction prices. The next subsection attempts to evaluate aspects of bid and ask behavior relative to the available theoretical models that might contribute to these properties.

### 6.3. Individual Bid and Ask Behavior

This final subsection presents individual bid and ask data from the random draws sessions to evaluate more carefully the bid and ask strategies suggested by the theoretical models. Because of learning this subsection reports data from periods 9 through 16—after an initial 8-period learning phase but before the shift in the underlying value and cost distributions. Results 11 and 12 provide stylized facts that will be useful in any assessment of how the EPA auction might perform under even more complex field environments. These results will also guide further theoretical work for the EPA auction institution in the random draws environment.

**RESULT 11:** In the EPA auction with random draws, the Multiple Unit Discriminative auction bidding strategies closely approximate the behavior of buyers.

**Support:** Figure 11 presents the bid for each value draw in periods 9-16 of the experienced EPA auction, random draws sessions. Over these periods buyers' bids reveal only 73.6 percent of the true valuations. The figure also indicates the theoretical risk neutral bid functions for  $Q=7$  and  $Q=8$  units offered. [The average number of units traded per period during these middle eight periods was 7.9 with a median and mode of 7.] As discussed in Section 5.3, we expect this model to provide an approximation to the buyers' strategy although it does not account for the endogeneity of the number of units offered by the strategic sellers. Judging from this figure this one-sided model appears to be a good approximation, even though neither the  $Q=7$  nor the  $Q=8$

theoretical bid functions are exactly appropriate given the uncertainty in the number of units offered. The empirical bid function (the figure also shows the OLS estimate) appears to asymptote in the correct price range, although bids in the value range between about 110 and 150 appear too high.<sup>15</sup> Because this equation is estimated precisely, an F-test rejects both the  $Q=7$  and  $Q=8$  risk neutral bid functions; however, the theoretical functions do provide a close approximation and bracket the observed equation.\*

**RESULT 12** In the EPA auction with random draws, the sellers follow ask strategies that are qualitatively similar to the “jump” strategy defined as part of a Nash equilibrium for the constant aggregate environment.

Support: Figure 12 presents the ask for each cost draw in the EPA auction, random draws sessions. This figure is a little misleading because the relative proportions of 1¢ and non-1¢ asks are not properly reflected. It does not illustrate the 223 1¢ asks for costs below 125, so Figure 13 presents the percentage of asks at 1¢ for different cost draw ranges. A discontinuity exists in the empirical ask function at a cost of about 125. Approximately 80 percent of the asks are 1¢ for units with cost draws less than or equal to 125, and two sellers submitted nearly all of the non-1¢ asks for these low-cost units (see below). Of the 374 asks during periods 9-16 in the four experienced EPA auction, random draws sessions, 97 were greater than cost (25.9 percent). However, most of the asks above cost were associated with high cost units that are unlikely to trade. Sellers have little incentive to enter serious asks for these units. Finally, the discontinuity described above applies to most individual sellers. A total of 16 individual sellers provide data from the four experienced EPA auction, random draws sessions. Two sellers never asked 1¢, but the remaining 14 asked 1¢ frequently. The risk of the 1¢ ask strategy appears minimal, as only 11 of the 223 1¢ asks in periods 9-16 (5 percent) resulted in a loss for the seller. We calculated the maximum cost draw associated with a 1¢ ask for each seller over these middle periods to estimate the ask function discontinuity point. The 14 sellers that ever asked 1¢ all had their ask function jump located in the interval [105, 129] (median 115.5).\*

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<sup>15</sup>Cox, Smith and Walker (1984) show that risk aversion implies bids above the risk neutral bid function shown in the figure for the one-sided multiple-unit discriminative auction.

Result 13 concerns the uniform price institution with random draws, and evaluates the aggregate empirical bid and ask functions relative to the very precise theoretical predictions for this environment.

**RESULT 13:** In the uniform price auctions, both buyers and sellers tend to reveal their true values and costs as predicted, especially at the margin.

**Support:** Figures 14 and 15 display bids and asks for the value and cost draws in periods 9-16 of the uniform price, random draws sessions. Dotted lines indicate truthful revelation (bid=value and ask=cost). The near-truthful revelation risk neutral equilibrium bid and ask functions from the Rustichini et al. (1994) Bayesian-Nash model are also indicated on the figures.<sup>16</sup> With very few exceptions all asks are greater than or equal to cost (Figure 14). The graph also indicates an OLS estimate of the empirical ask function (pooling across all sellers). The estimate is almost identical to the theoretical ask function, and an F-test does not reject the hypothesis that the parameters are equal to the theoretical prediction ( $F_{2,238}=0.84$ ). There is more dispersion in the bids relative to value (Figure 15). Averaged over all bids on this figure, buyers' bids reveal over 99 percent of the true valuations, much greater than the 73.6 percent revealed in the EPA auction sessions. Note that most of the bid dispersion exists for low and high values; the bids associated with these values are unlikely to affect prices so buyers have low opportunity cost from suboptimal bidding. The values that affect price are typically between 100 and 150, and less bid dispersion exists for values in this range. The graph shows the OLS estimate of the empirical bid function (pooling across all buyers). An F-test rejects the theoretical prediction ( $F_{2,207}=7.66$ ).•

## 7. CONCLUSION

The Environmental Protection Agency has created a unique call auction institution for trading sulfur dioxide emission allowances. The major difference between the EPA auction institution and more traditional call auctions is that successful buyers pay their bid price and

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<sup>16</sup>The key differences between this laboratory test and the assumptions underlying the Rustichini et al. model are (1) the experiments endow traders with multiple-unit trading capacities and (2) the laboratory subjects may not be risk neutral.

successful sellers receive the bid price of some specific buyer. This research examines the implications of this particular call auction procedure.

The primary conclusion of this experiment is that these auction rules create strong incentives for both buyers and sellers to under-report their true cost of emissions control to the auction. Consequently, compared to more standard uniform price call auctions, the EPA auction generates lower market-clearing prices and extracts less gains from exchange. Efficiency increases over time in the uniform price auction but not in the EPA auction. The EPA auction is also less responsive to and recovers slowly from changes in underlying market conditions. The prices reported in the EPA auction, having been modified by its strategic considerations, are less accurate reflections of the true economic circumstances than are the prices reported in the uniform price auction. This shortcoming is important because emissions trading is expected to provide valuable information to utilities. Utilities need accurate and timely information concerning the market value of emission allowances to ensure cost-effective investments in emission control.

The EPA auction interacts with other markets, but to date no other centralized markets have evolved for these emission allowances in spite of encouragement by the EPA. A small number of privately brokered trades have occurred, but it would be unfortunate to rely on this kind of trading because of the significant transactions costs of search and bilateral negotiation. The annual EPA auction is the best opportunity for low transaction cost trading, but the two auctions held to date (in March of 1993 and 1994) were successful only in the public relations sense. Virtually no trades occurred other than for the mandatory units withheld by the EPA, a tiny fraction of the overall trading volume needed for substantial cost savings from tradable allowances. Prices for 1995 allowances typically ranged between \$140 and \$150, well below most analysts' expectations and below the \$180 to \$200 price range observed for allowances traded through private negotiation (Allowance Market Monitor, 1994). The slow development of this market is undoubtedly due to a variety of reasons—including regulatory uncertainty and political constraints—but we believe that it is substantially handicapped by the unique auction rules studied here.

Important theoretical issues remain unresolved. In general, the EPA auction is too complicated to solve with the classical techniques of auction theory. Closed form bidding functions for the random draws environment have not been obtained, and numerical methods could not be applied successfully because of the complexity of this auction process. Nevertheless, we do obtain theoretical solutions for the special case considered in the constant aggregate environment, and the data support this model. This special case and models derived from simplifying assumptions also generate theoretical predictions for the more complex random draws case, and these implications are also supported by the data. However, additional theoretical work is needed.

Important historical and practical issues also remain open. Why did the EPA create such an unusual auction process, and is it possible to change the auction rules? The following quote suggests that the discriminative auction rules are a result of an EPA interpretation of the Act perhaps guided by faulty intuition about the nature of auction processes:<sup>17</sup>

EPA interprets this provision [of the Act] to require that allowances be sold to successful bidders at the price of their respective bids (also referred to as a discriminative approach). As a result, the total proceeds of each auction, which are to be paid to the initial allowance-holders, *will be greater than they would be if bidders were required to pay only the auction-clearing price* (or lowest successful bid price) regardless of the stated price in their respective bids. This outcome appears consistent with the statutory requirement that allocation proceeds be transferred to original allowance-holders (emphasis added).

Ironically, the research reported here suggests that the rules adopted by the EPA have an impact that is opposite of their intent, because buyers bid lower in discriminative auctions. The EPA was aware that “such a system may provide incentives for holders of allowances to specify lower minimum prices for allowances than they would be willing to accept in order to be matched to higher bids.”<sup>18</sup> However, it seems unlikely that the EPA was aware of the full implications of these rules. Not only do the rules foster lower market-clearing prices than either competitive levels or prices that would be generated under more standard auction rules, but the rules foster several other undesirable side effects.

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<sup>17</sup>*Federal Register* [1991a], page 23746.

<sup>18</sup>*Ibid.*



Can the rules be changed? The language of the Clean Air Act states that allowances “shall be sold on the basis of bid price.” However, the Act does *not* explicitly state that prices must be set equal to the different bid prices and the language does not exclude the possibility that the ask price be part of the price determination equation. Indeed, transaction prices are determined by both the bid and ask prices in the current EPA auction rules. If this statement of the Act is sufficiently ambiguous—which is a legal rather than economic question—then the doctrine of judicial deference allows the EPA to employ any “reasonable” statutory interpretation in setting up the auction.<sup>19</sup> Because of the absence of any further restraining language it would seem that the uniform price auction rules are consistent with the Act. Our recommendation is that the EPA seriously consider adopting alternative rules such as the uniform price auction institution.

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<sup>19</sup>See *Chevron, U.S.A., Inc. v. Natural Resources Defense Council*, 467 U.S. 837 (1984).

**Table 1:**  
**Summary of Sessions and Parameters**

Experiment Name	Trading Institution	Environment for periods 1-16	Environment for periods 17-24	Subject Experience
EPACon1	EPA	constant (CE=230)	constant (CE=290)	none
EPACon2	EPA	constant (CE=230)	constant (CE=290)	none
EPACon3	EPA	constant (CE=230)	constant (CE=290)	none
UNIcon1	UNIFORM	constant (CE=230)	constant (CE=290)	none
UNIcon2	UNIFORM	constant (CE=230)	constant (CE=290)	none
EPARan2x	EPA	random [0, 250]	random [0, 300]	in EPA/constant
EPARan3x	EPA	random [0, 250]	random [0, 300]	in EPA/constant
EPARan4x	EPA	random [0, 250]	random [0, 300]	in EPA/constant
EPARan5	EPA	random [0, 250]	random [0, 300]	none
EPARan6x	EPA	random [0, 250]	random [0, 300]	in EPA/random
UNIRan1x	UNIFORM	random [0, 250]	random [0, 300]	in uniform/constant
UNIRan2x	UNIFORM	random [0, 250]	random [0, 300]	in uniform/constant

**Table 2:**  
**Summary of Treatment Conditions and Experimental Design**

	EPA Auction	Uniform Price Auction
Constant Aggregate	3 inexperienced	2
Random Draws	1	0

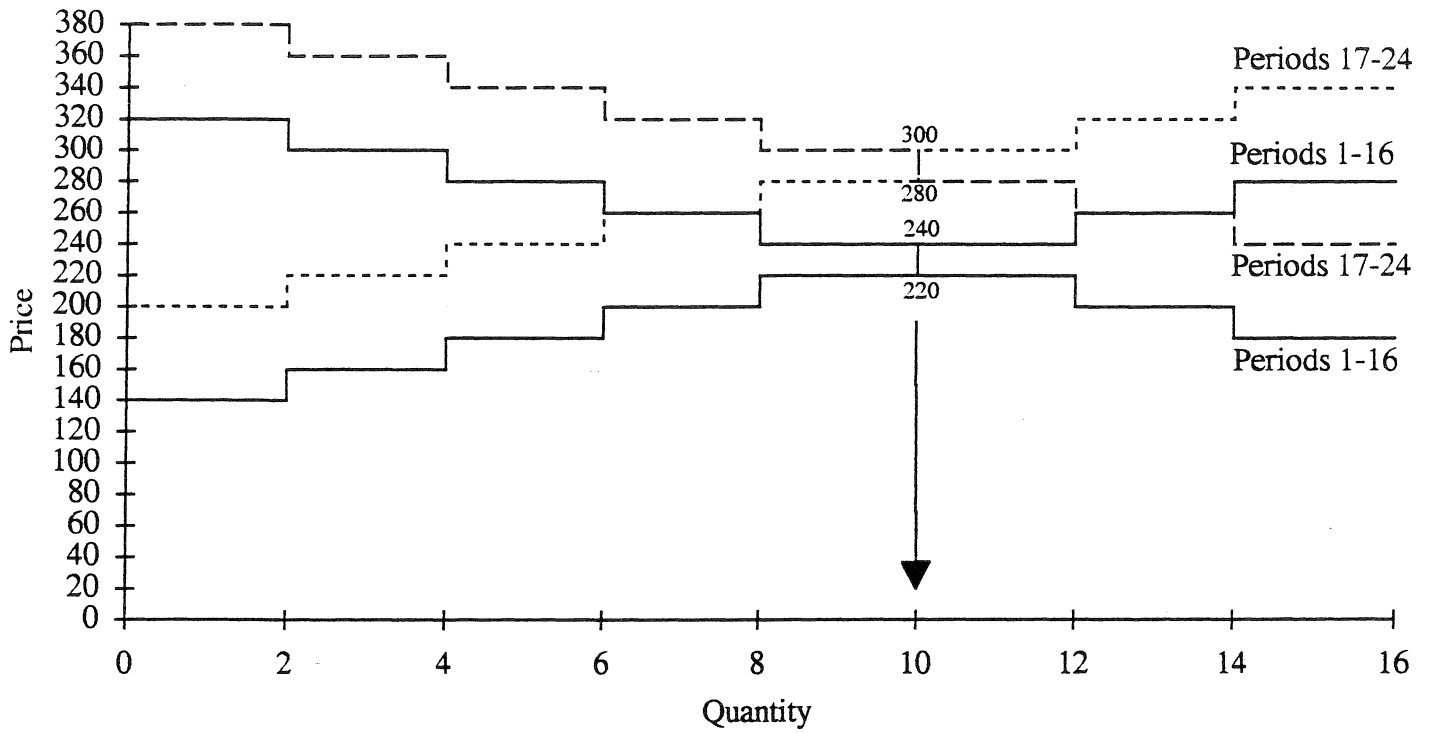
  

0	0
experienced	
4	2

**Table 3:**  
**Summary of Model Implications**

	EPA Auction	Uniform Price Auction
Constant Aggregate	Buyer Strategy	Elbow Shape
	Seller Strategy	Revealing Values at margin
	Price and Quantity	Revealing Costs at margin
	Market Efficiency	$240 \geq P \geq 220$ in Periods 1-16 $300 \geq P \geq 280$ in Periods 17-24 $Q=10$
Random Draws	Buyer Strategy	Near 100 Percent
	Seller Strategy	Near 100 Percent
	Price and Quantity	Revealing Values
	Market Efficiency	Revealing Costs

**Figure 1:**  
Demand and Supply in Constant Aggregate Environment (4 Units per Trader)



**Figure 2:**  
Elbow and Jump Strategies for the EPA Auction (Periods 1-16)

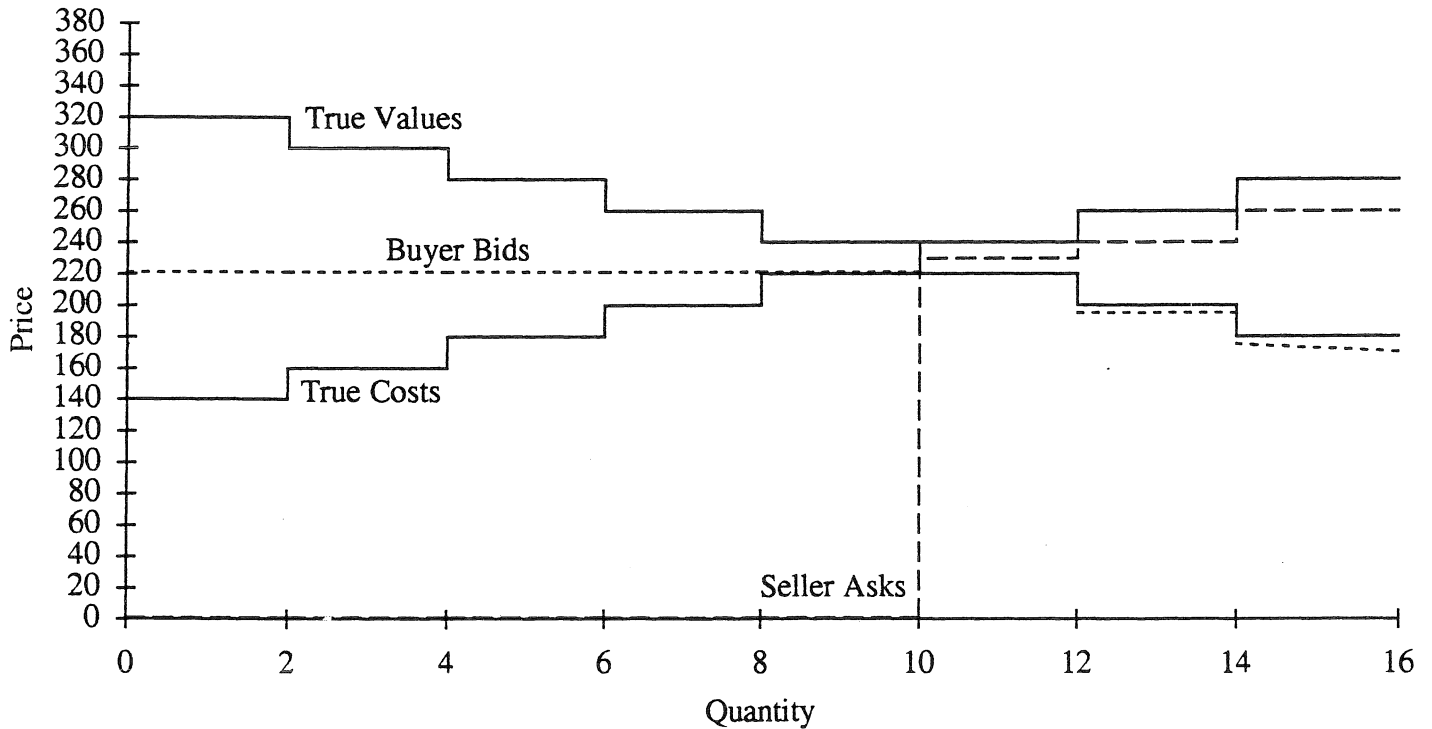


Figure 3(a):  
Session EPACon2 (CE price interval [220, 240]); Periods 1-8

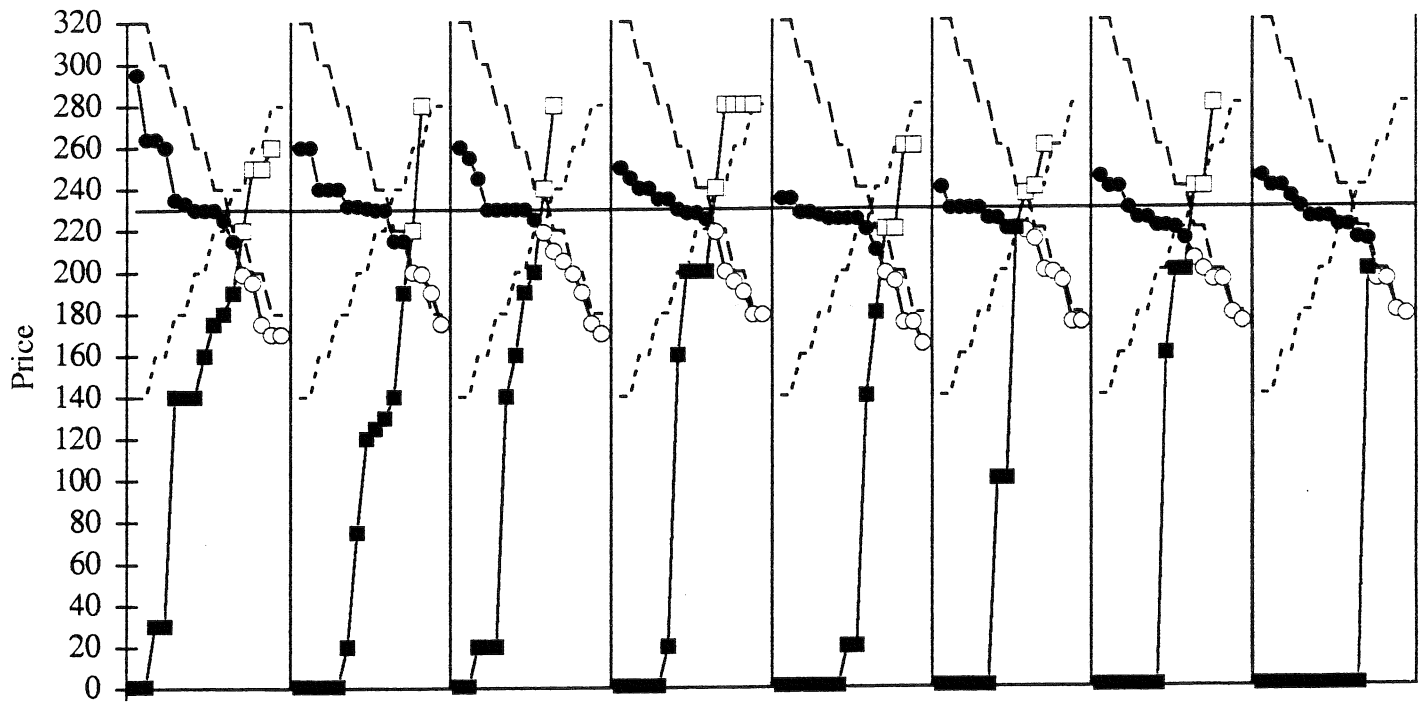


Figure 3(b):  
Session EPACon2 (CE price interval [220, 240]); Periods 9-16

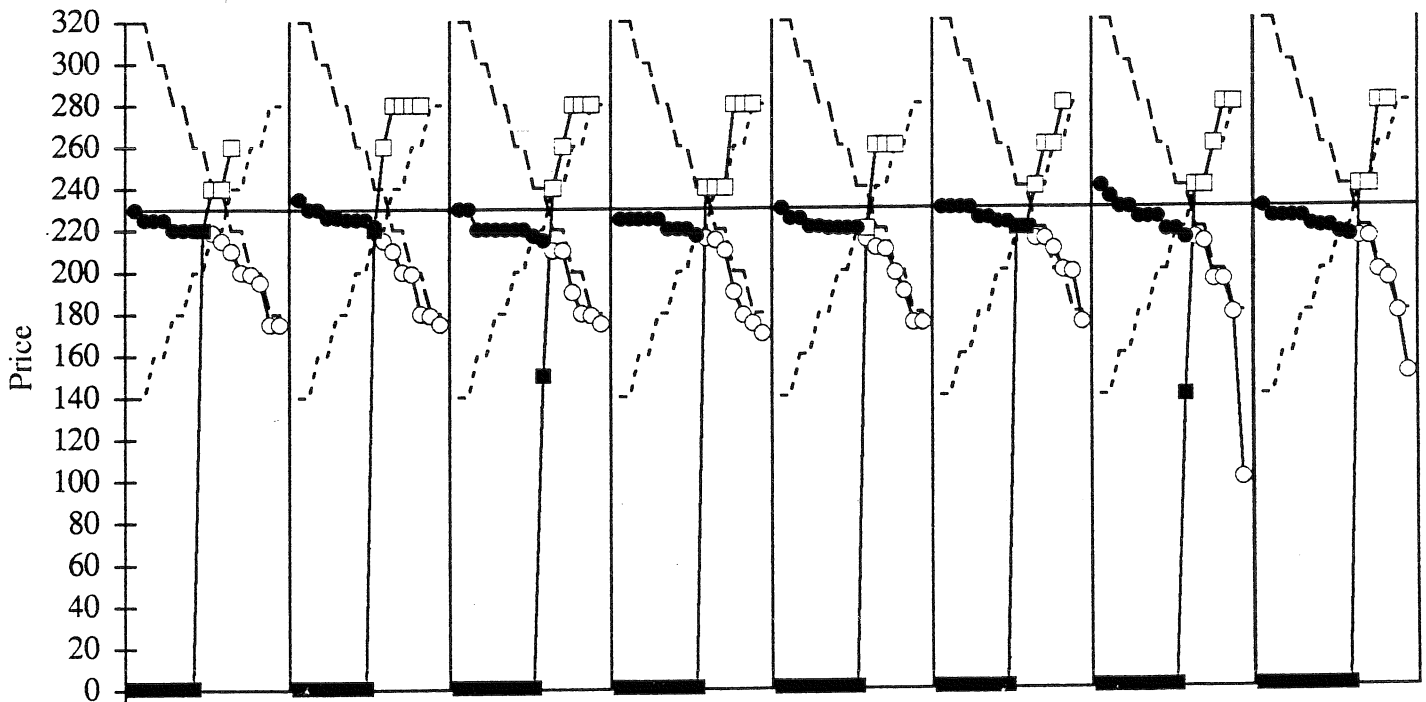
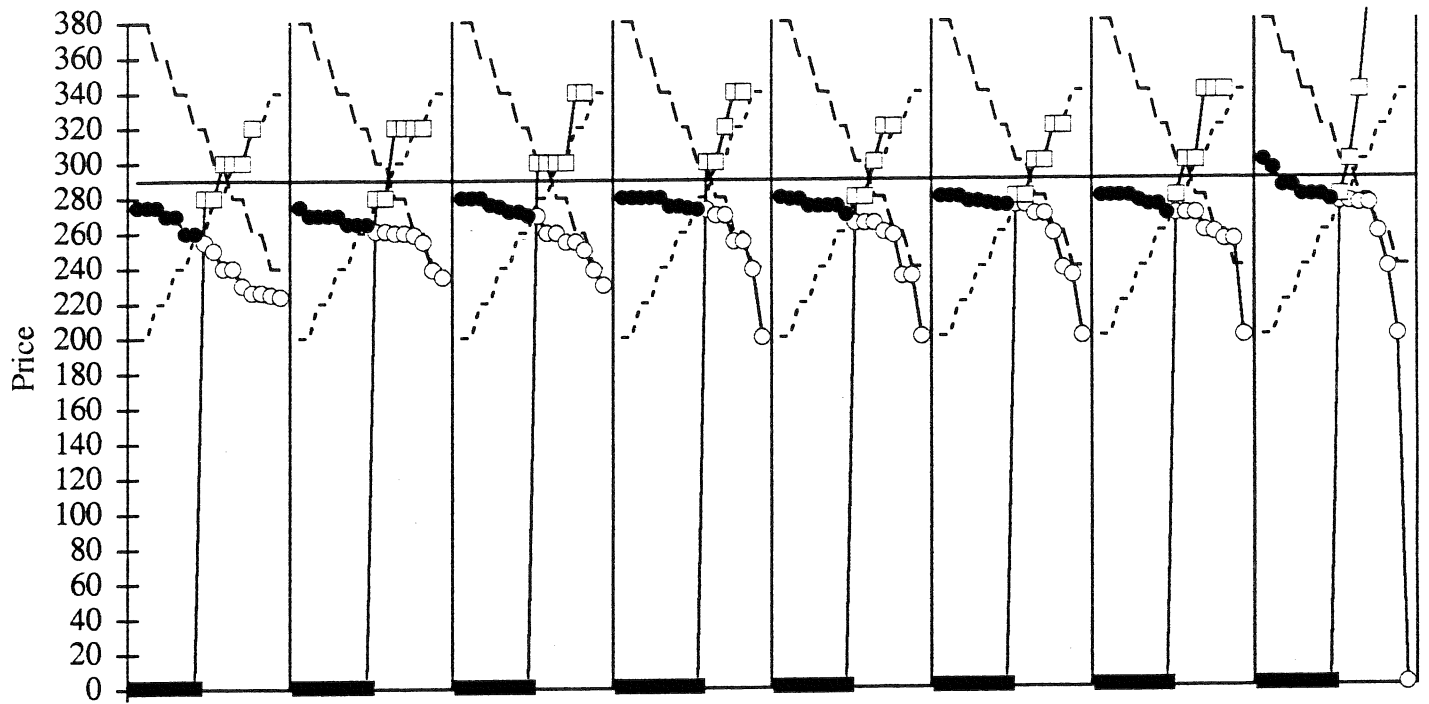
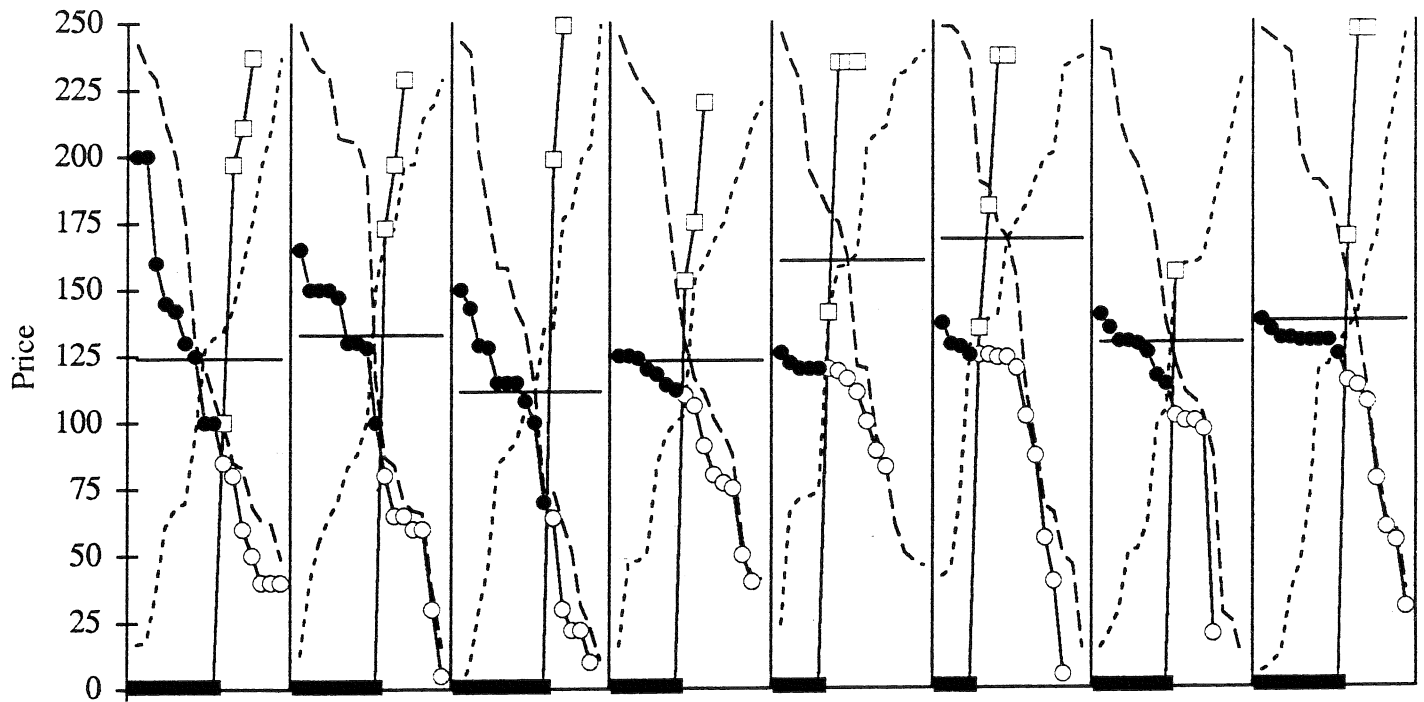


Figure 3(c):  
Session EPACon2 (CE price interval [280, 300]); Periods 17-24



**Figure 4(a):**  
Session EPARan2x (random draws from  $U[0,250]$ ); Periods 1-8



**Figure 4(b):**  
Session EPARan2x (random draws from  $U[0,250]$ ); Periods 9-16

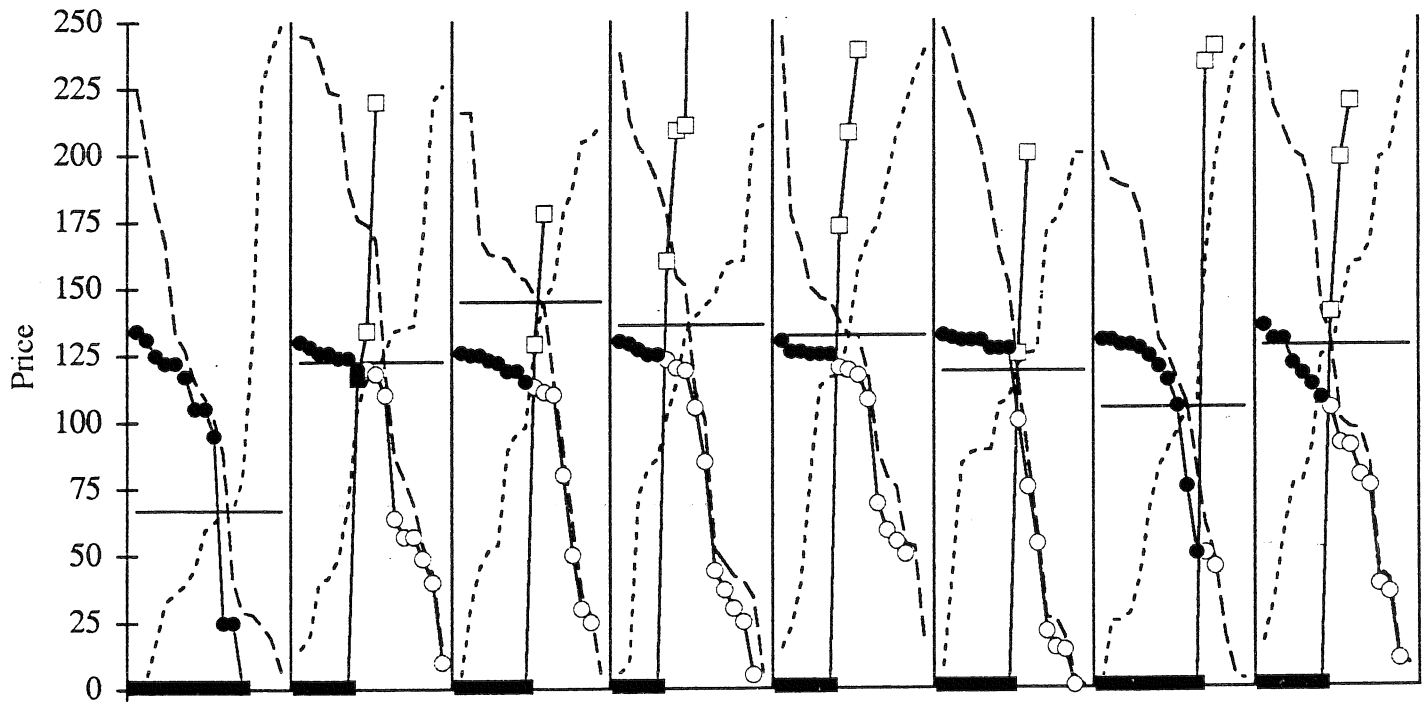
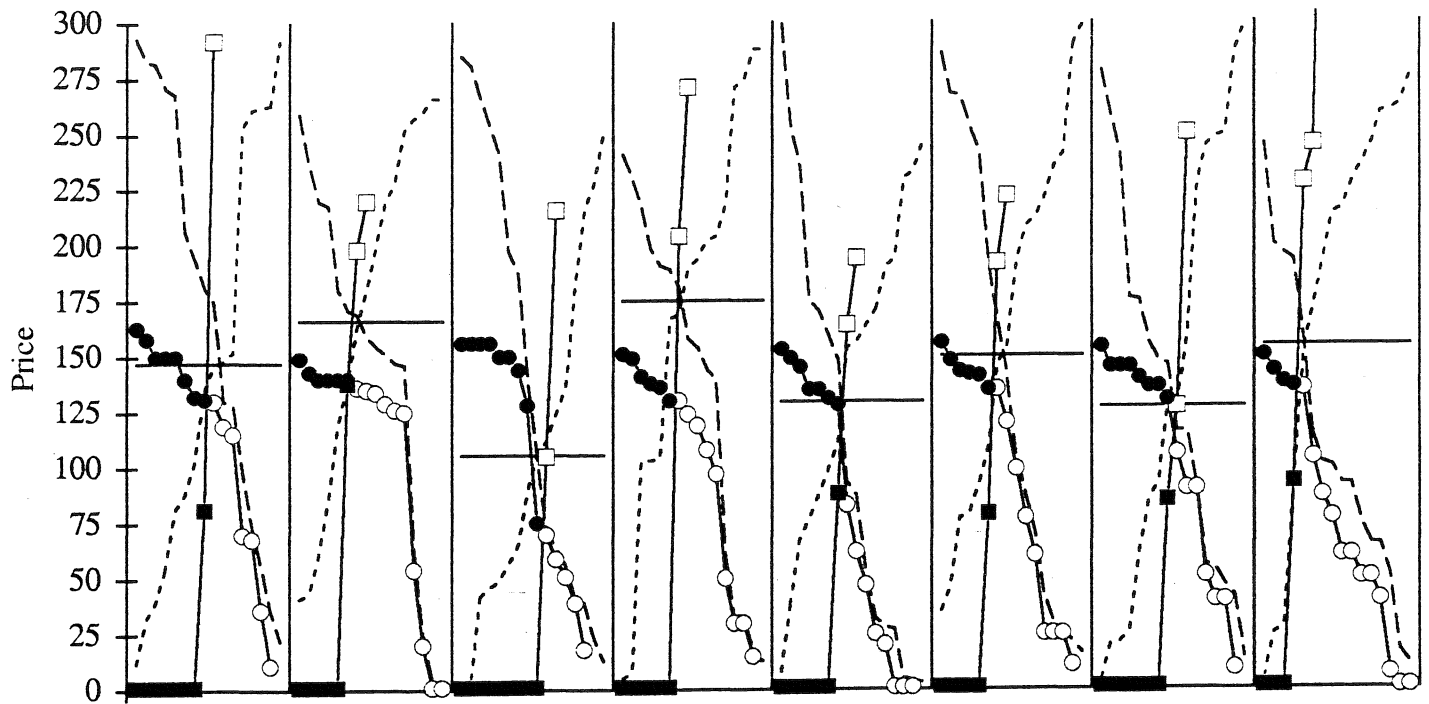
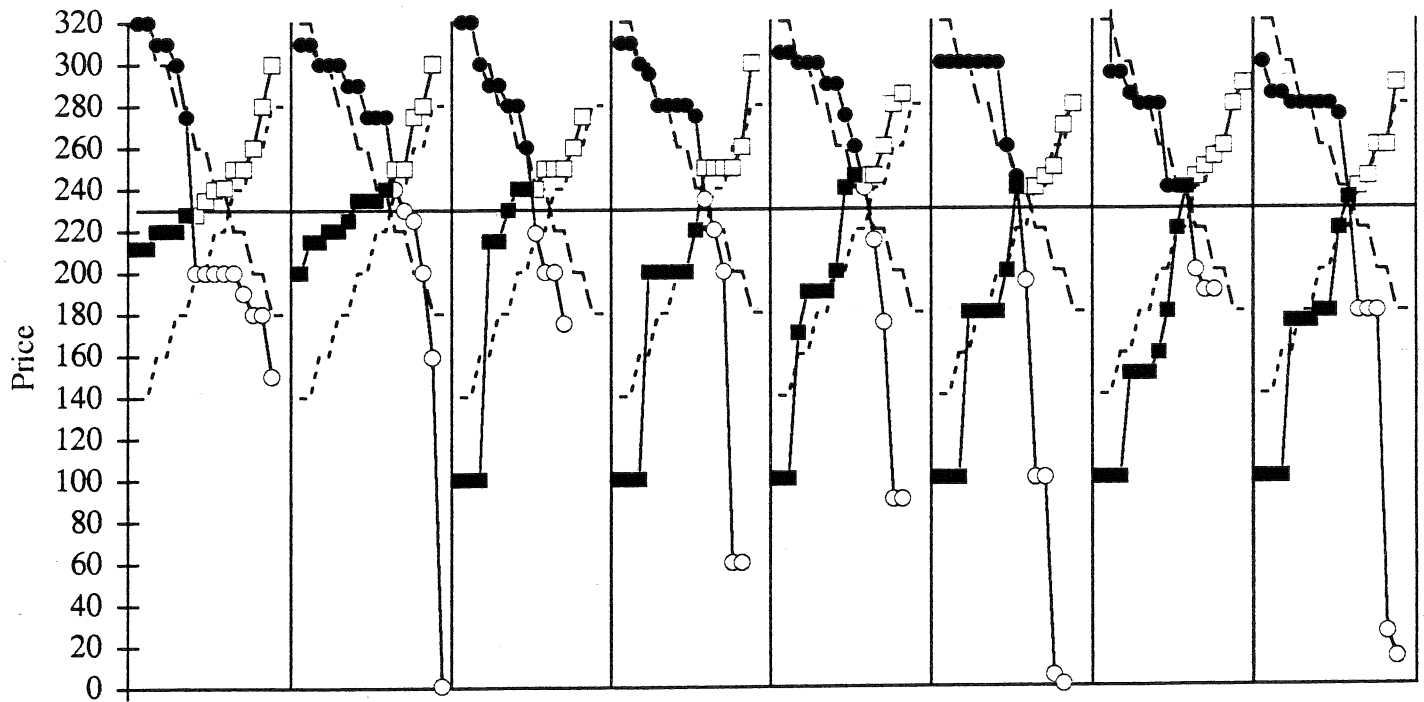


Figure 4(c):  
Session EPARan2x (random draws from  $U[0,300]$ ); Periods 17-24



**Figure 5(a):**  
Session UNICon1 (CE price interval [220, 240]); Periods 1-8



**Figure 5(b):**  
Session UNICon1 (CE price interval [220, 240]); Periods 9-16

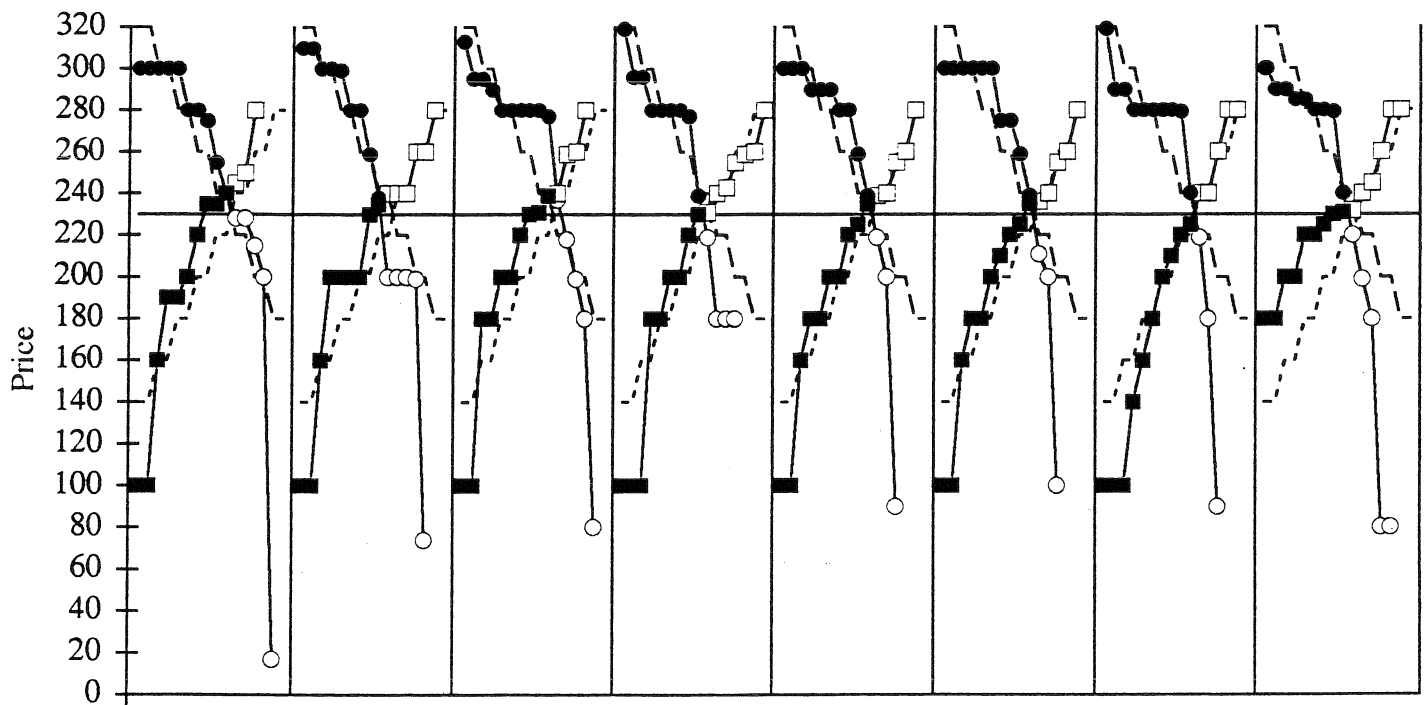
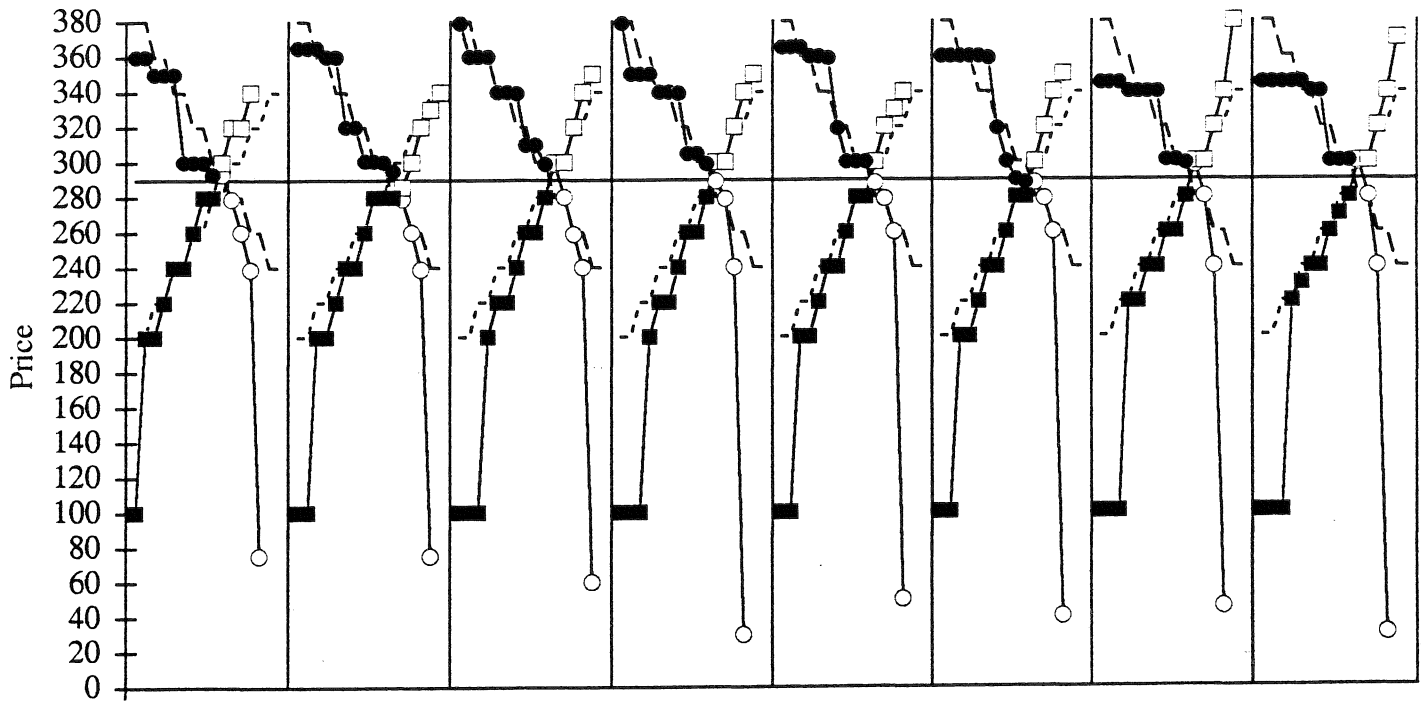
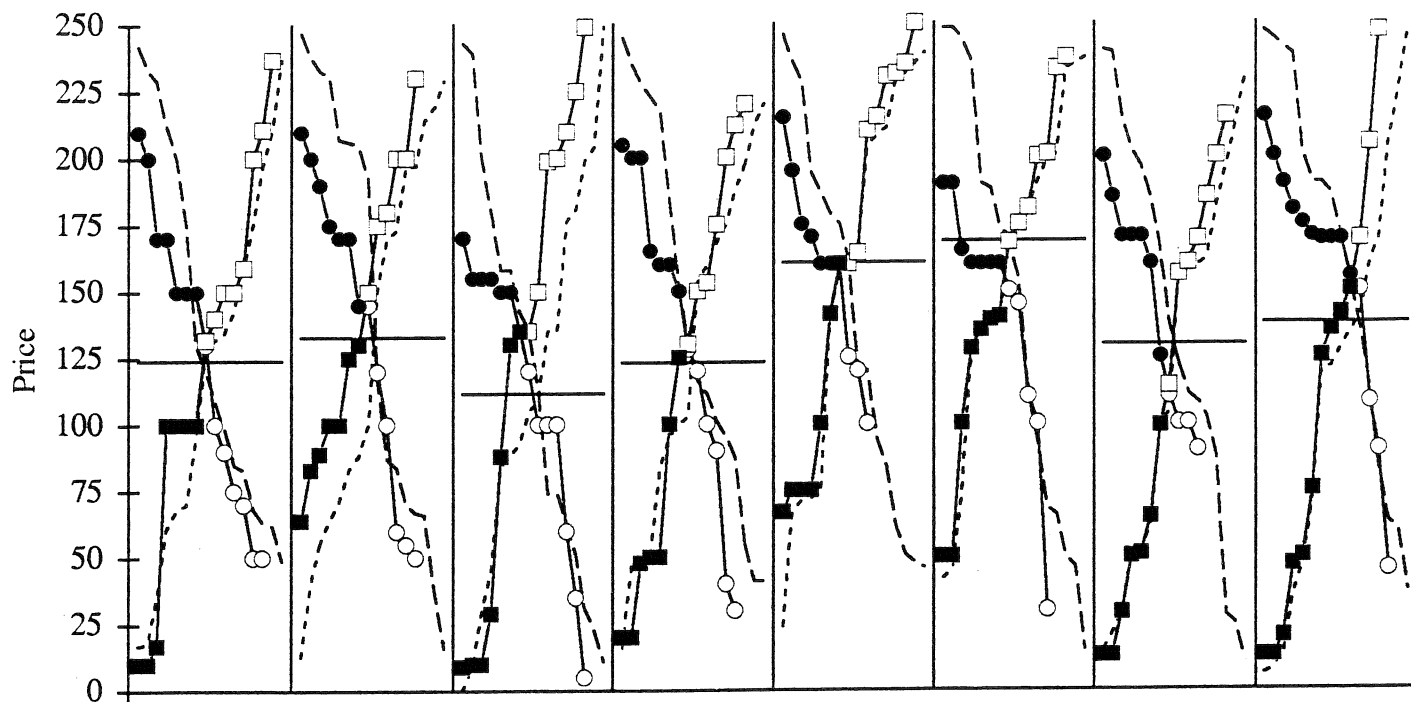




Figure 5(c):  
Session UNICon1 (CE price interval [280,300]); Periods 17-24



**Figure 6(a):**  
Session UNIRan2x (random draws from  $U[0,250]$ ); Periods 1-8



**Figure 6(b):**  
Session UNIRan2x (random draws from  $U[0,250]$ ); Periods 9-16

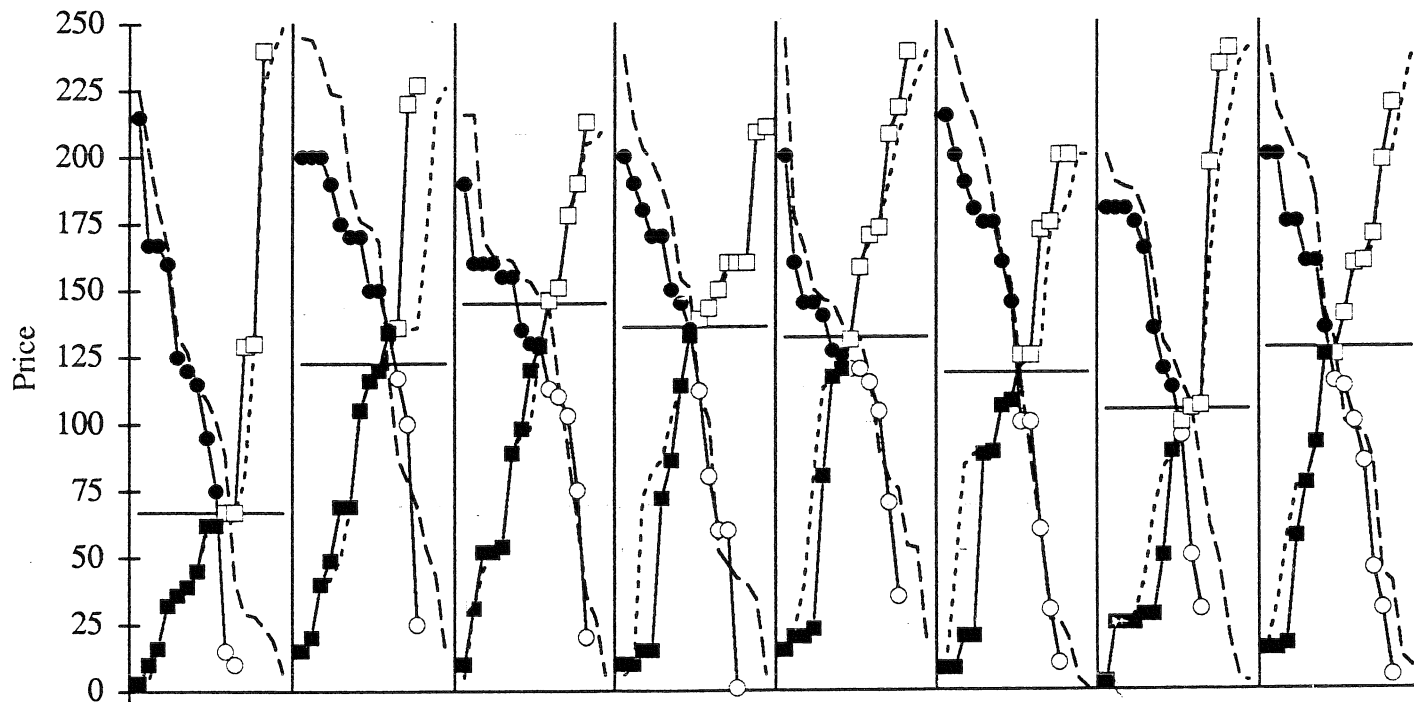
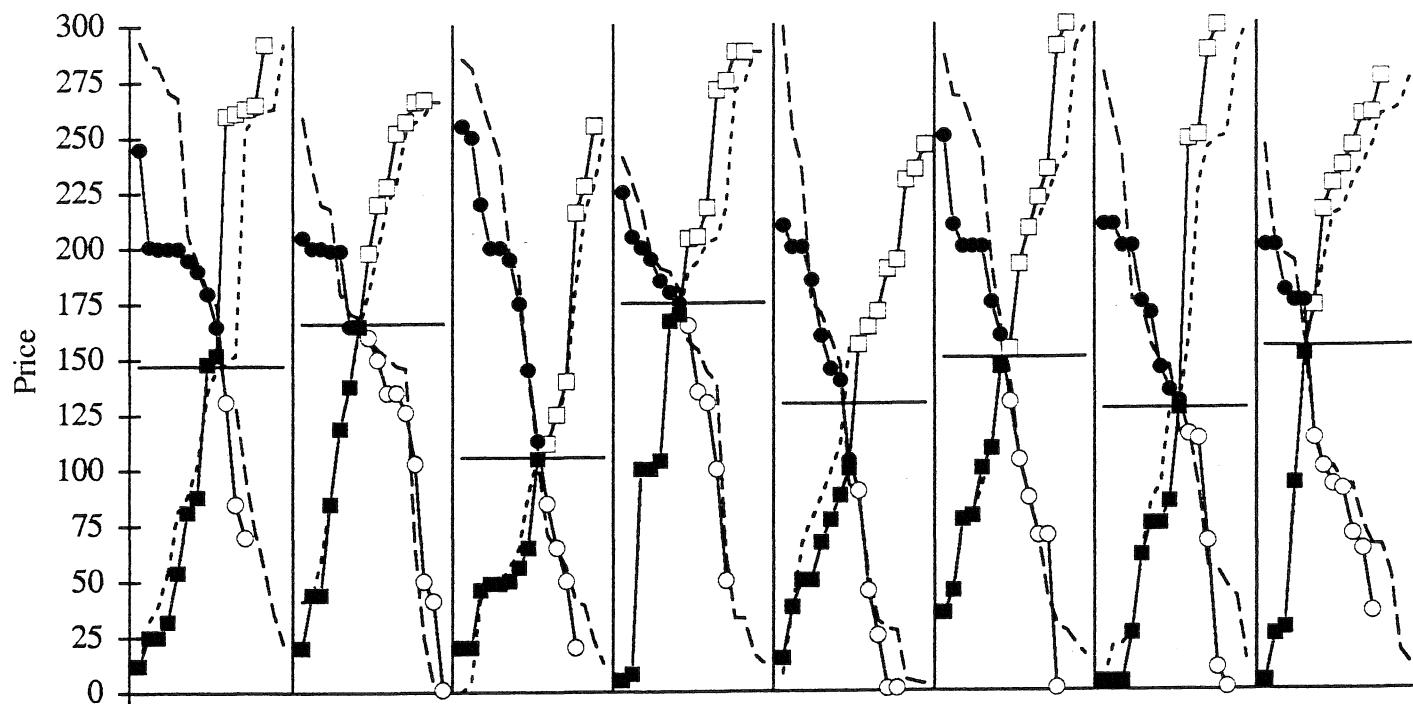
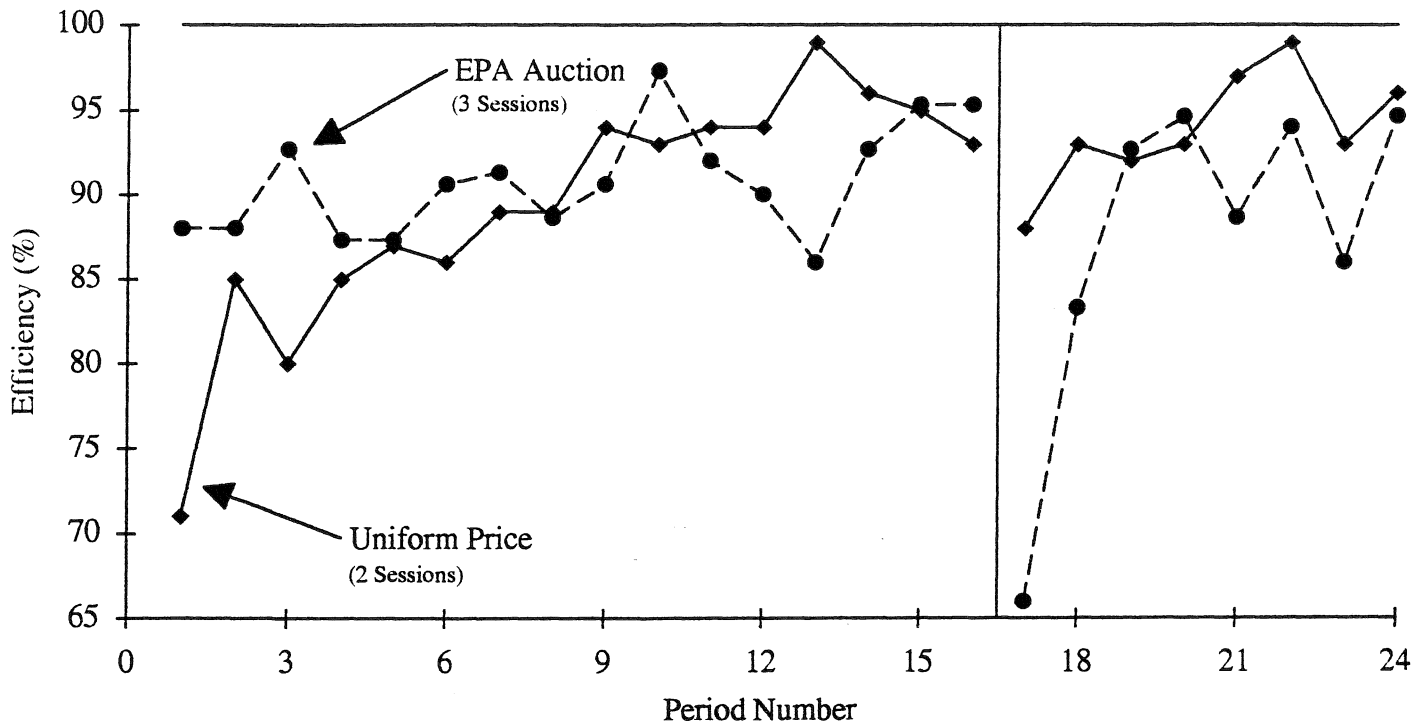


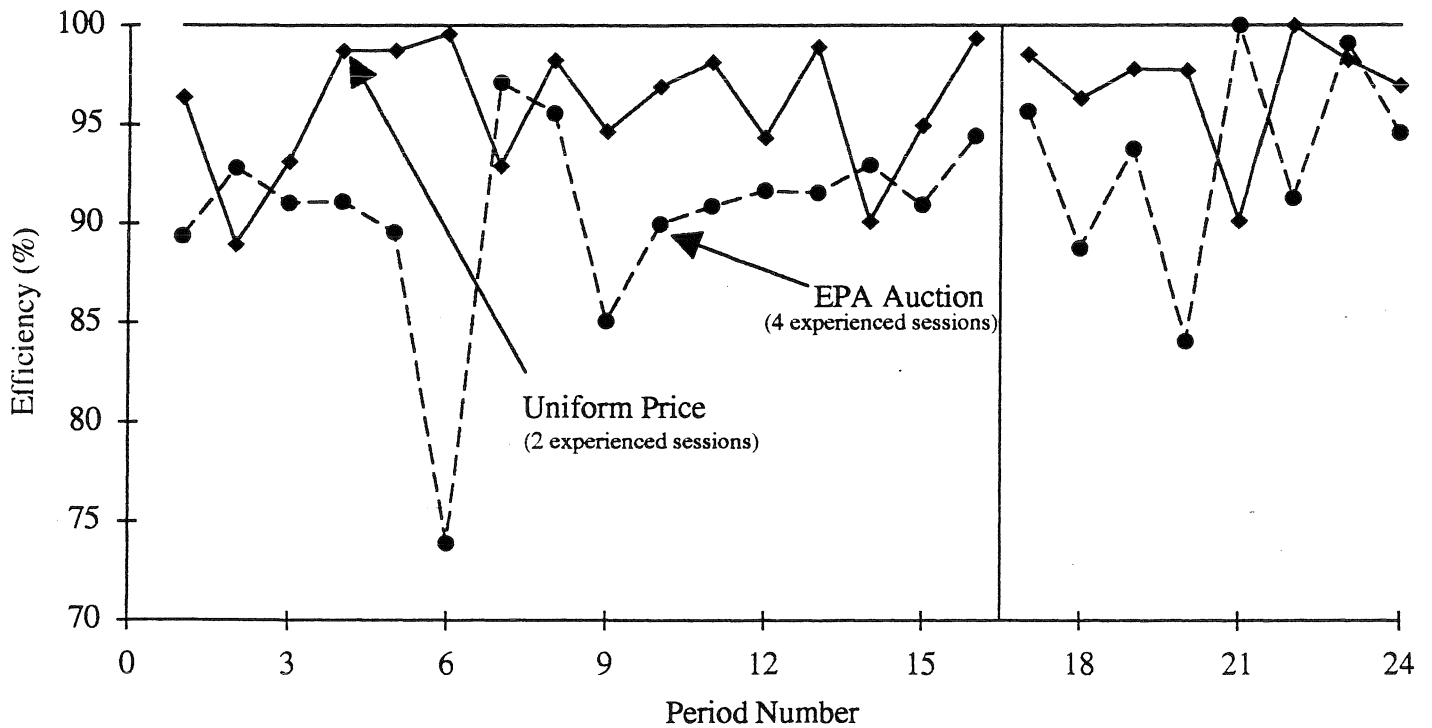
Figure 6(c):  
Session UNIRan2x (random draws from  $U[0,300]$ ); Periods 17-24



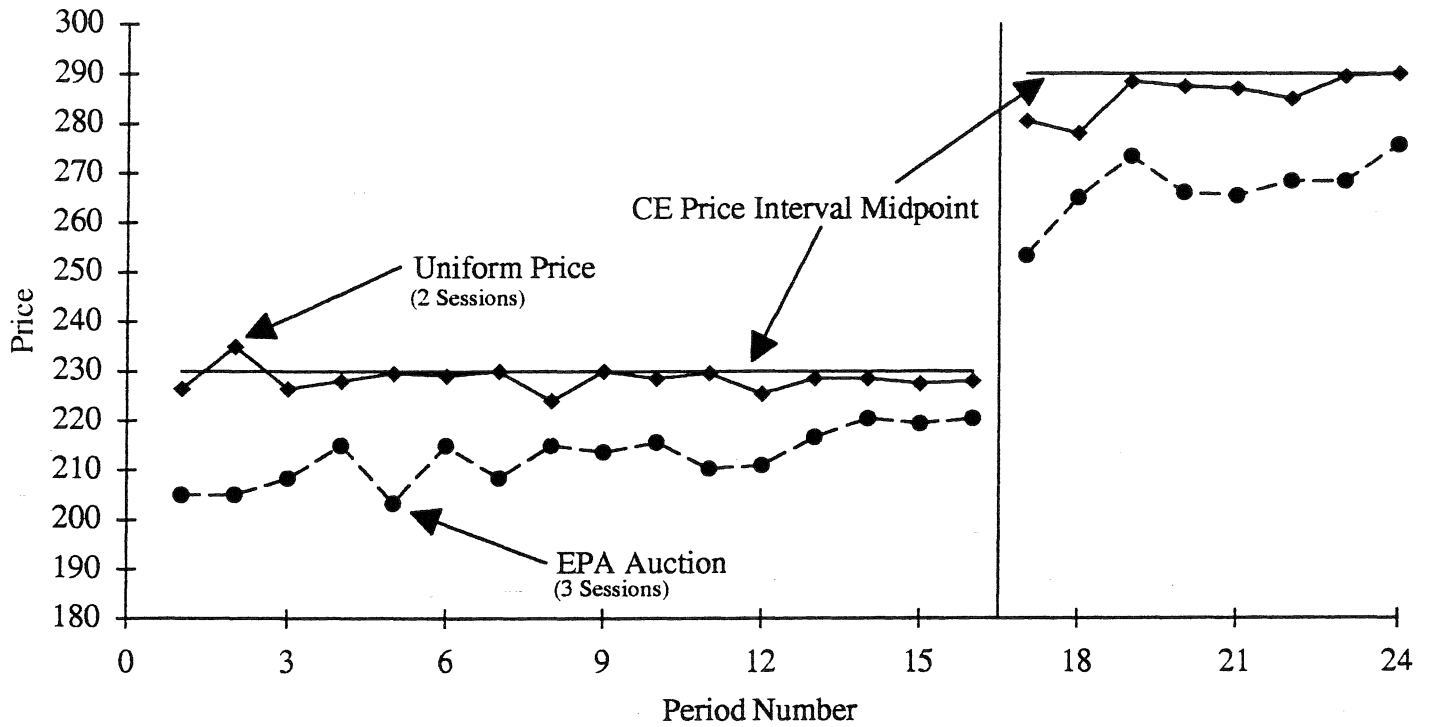
**Figure 7:**  
Average Efficiency in Constant Aggregate Environment



**Figure 8:**  
Average Efficiency in Random Draws Environment



**Figure 9:**  
Average Market-Clearing Prices in Constant Aggregate Environment



**Figure 10:**  
Average Market-Clearing Prices in Random Draws Environment

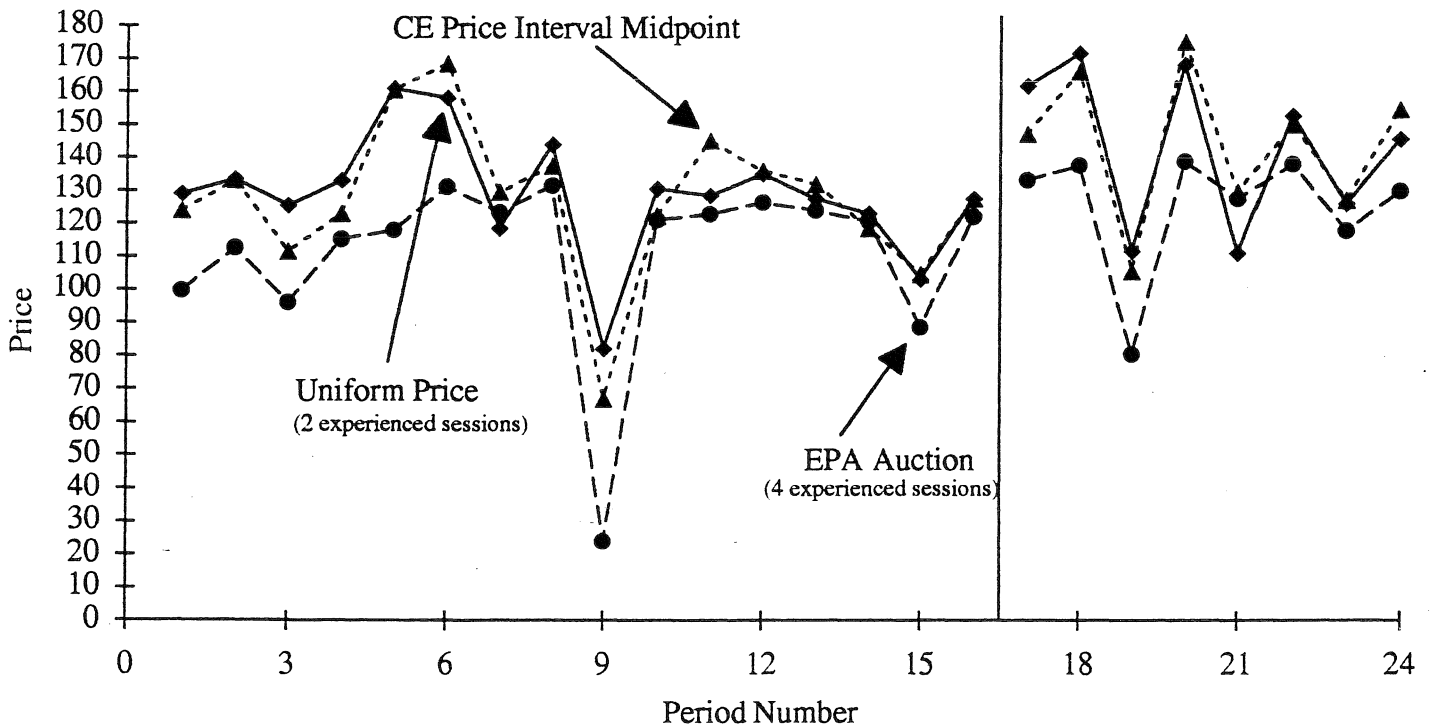
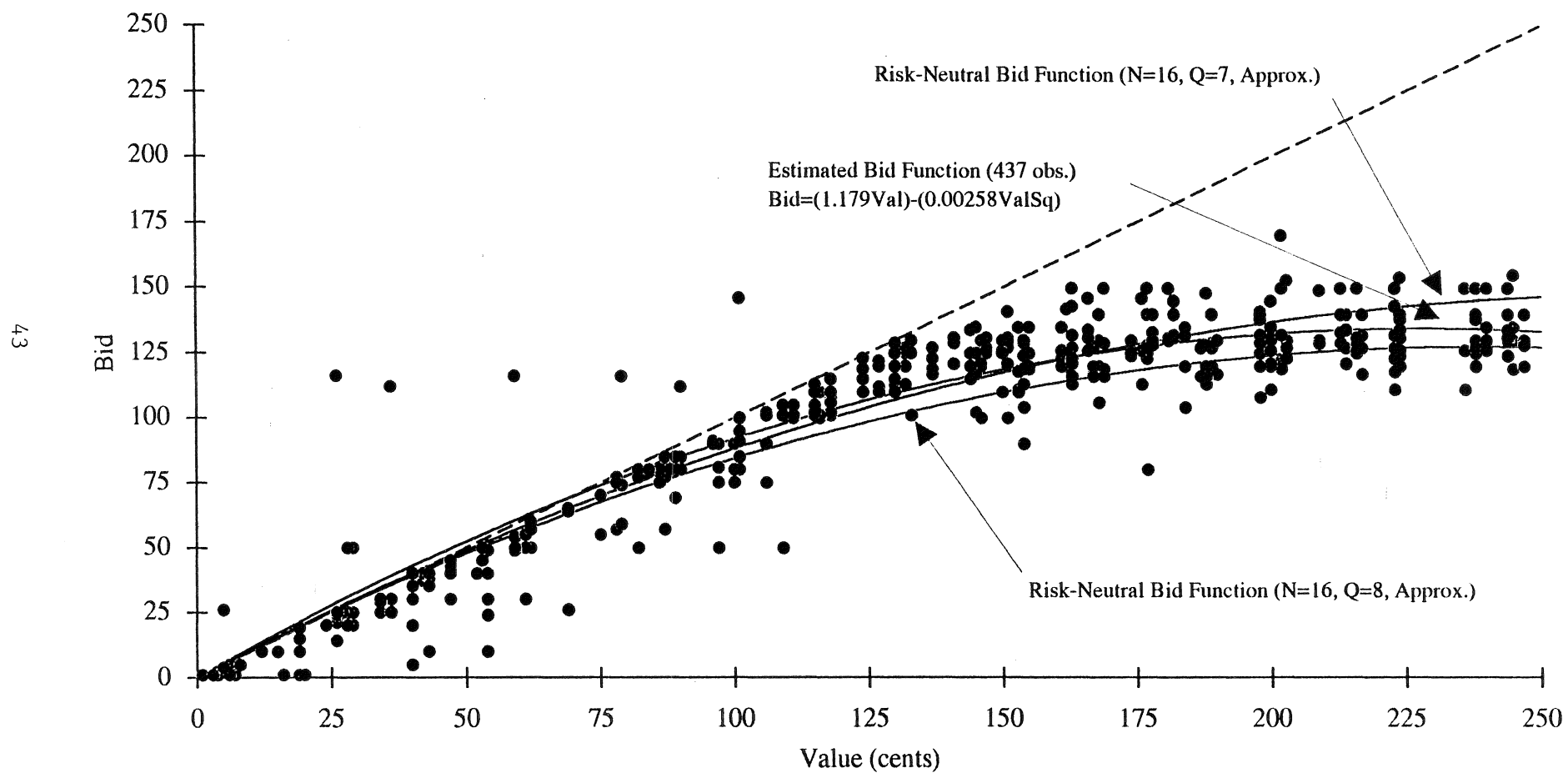
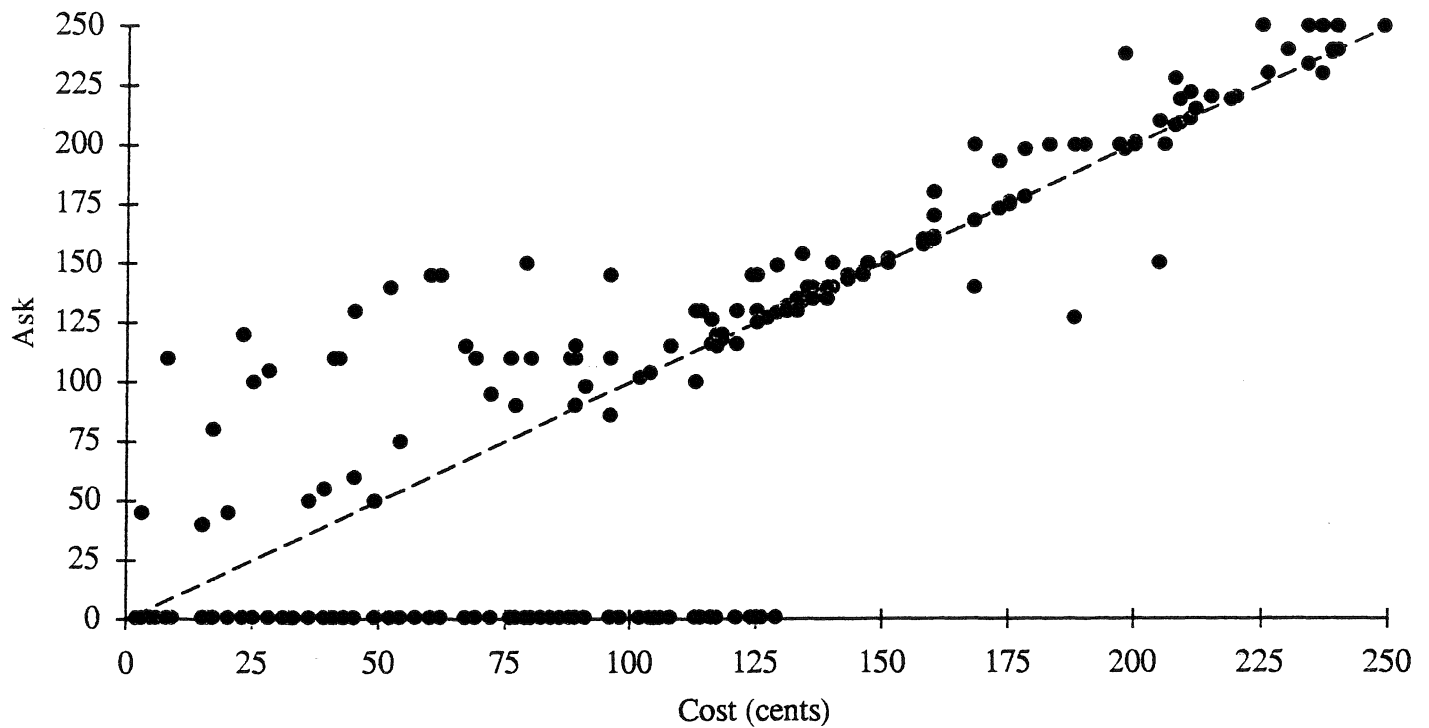


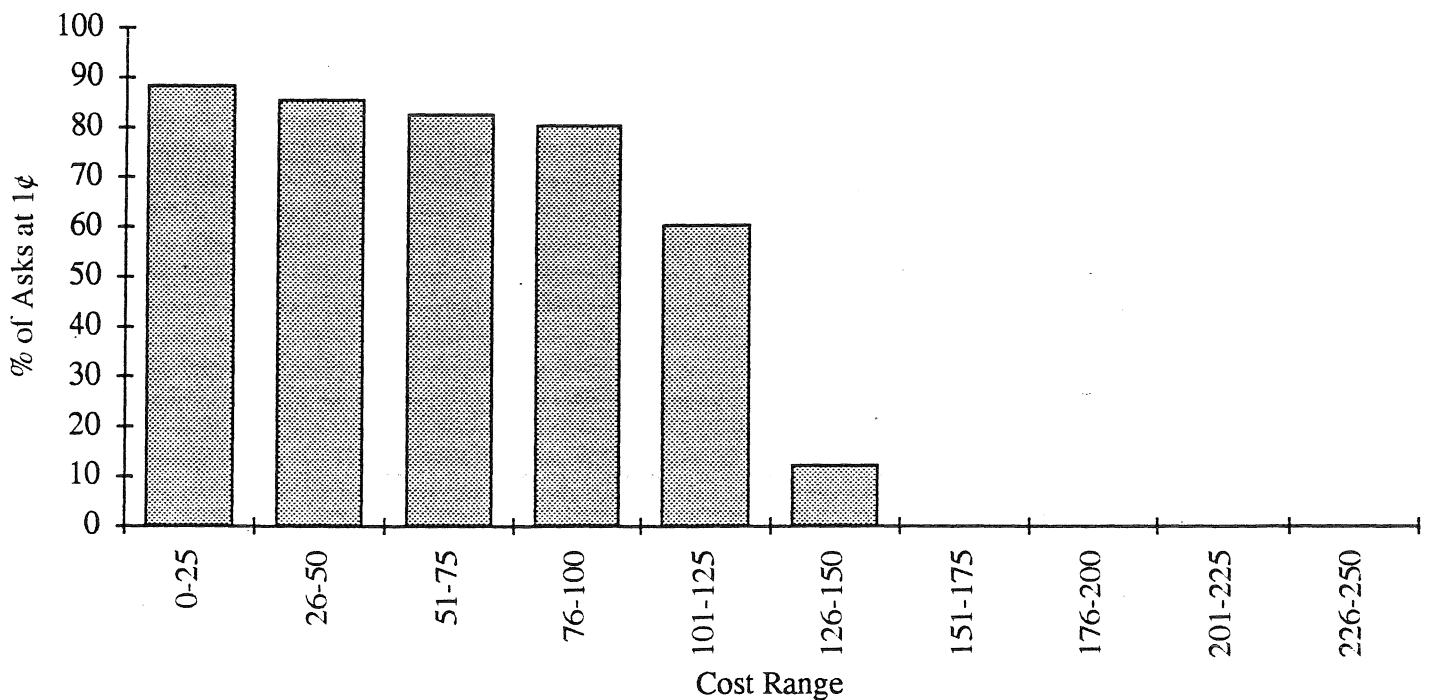
Figure 11:  
Bids for 4 Experienced EPA Auction/Random Draw Sessions: Periods 9-16



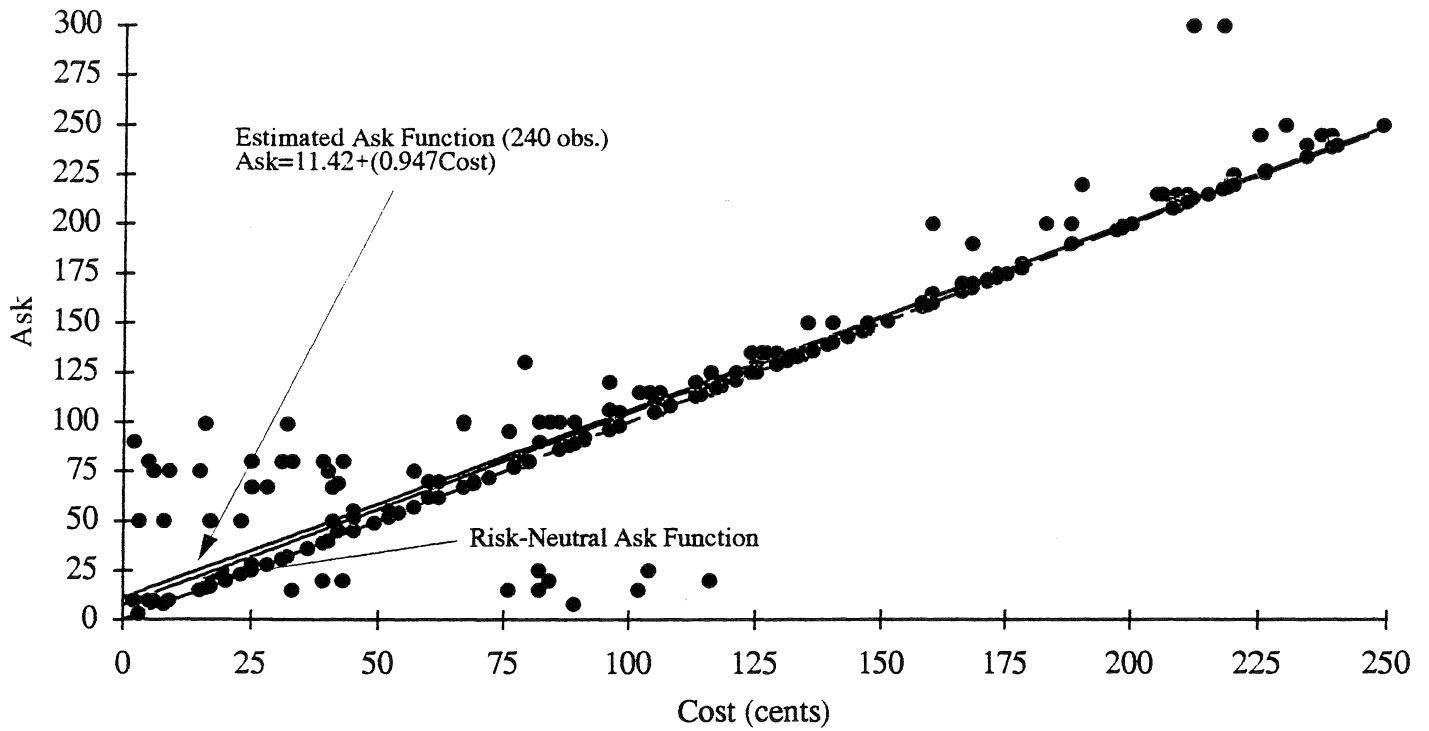
**Figure 12:**  
**Asks for 4 Experienced EPA Auction/Random Draw Sessions: Periods 9-16**



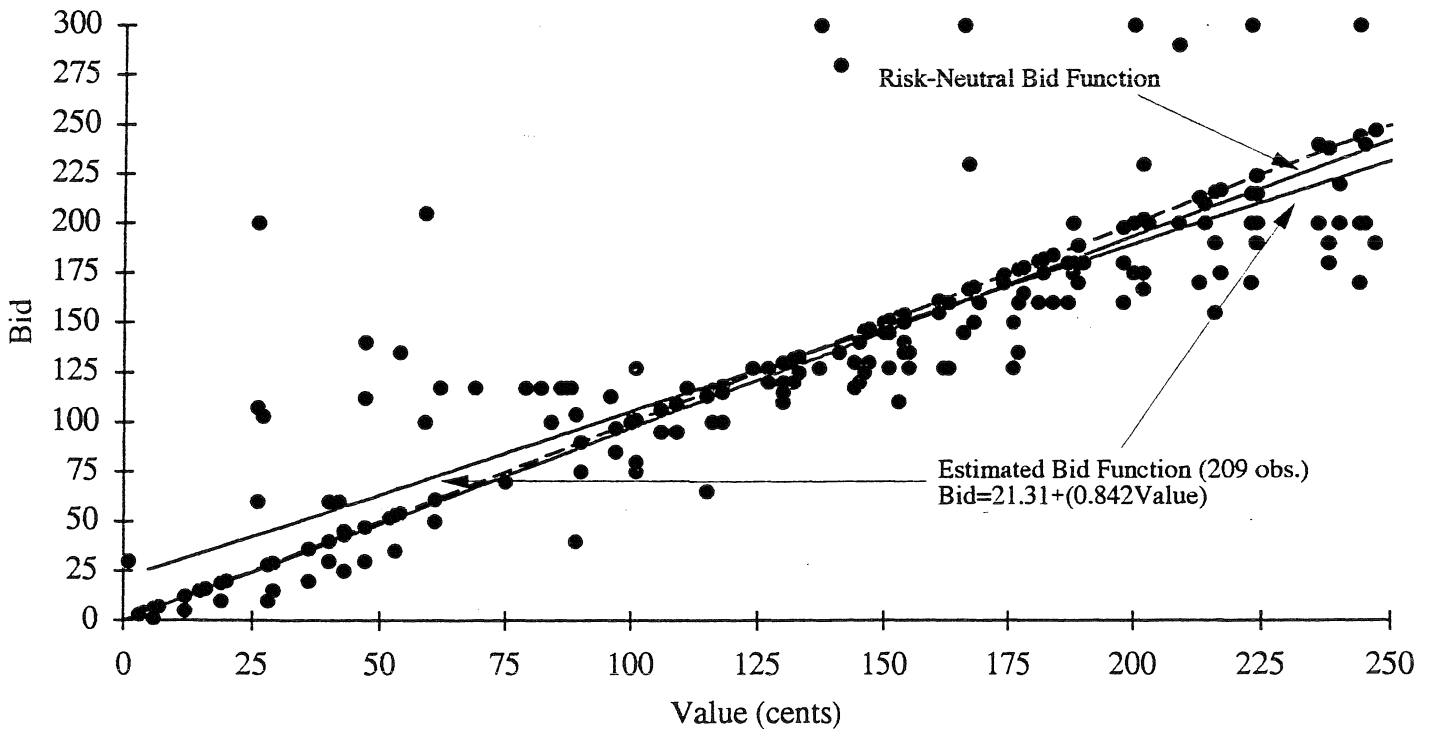
**Figure 13:**  
**Percentage of 1¢ Asks for Different Cost Ranges in 4 Experienced EPA Auction/Random Draw Sessions: Periods 9-16**



**Figure 14:**  
Asks for 2 Uniform Price/Random Draw Sessions: Periods 9-16



**Figure 15:**  
Bids for 2 Uniform Price/Random Draw Sessions: Periods 9-16





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## APPENDIX:

### INSTRUCTIONS FOR EPA AUCTION/CONSTANT AGGREGATE SESSIONS *INTRODUCTION*

This is an experiment in the economics of market decision making. Various research support agencies have provided funds for the conduct of this research. The instructions are simple, and if you follow them carefully and make good decisions you may earn a **CONSIDERABLE AMOUNT OF MONEY** which will be **PAID TO YOU IN CASH** at the end of the experiment.

Before you make any market decisions in this experiment, you will be given a starting capital credit balance of \$5.00. Any profit earned by you in the experiment will be added to your starting capital, and any losses incurred by you will be subtracted from your starting capital. If your losses exceed \$5, so that you have no money remaining in your current balance, you will be excused from the experiment. If you make your decisions carefully, this is highly unlikely. At the end of the experiment your net balance will be paid to you in cash.

In this experiment, we will create a market in which you will act as either a buyer or a seller of a commodity in a sequence of trading periods. You will earn profits by trading units each period. You will record your decisions and earnings on the Record Sheet that I am now passing out. Trading periods are denoted by separate columns. There will be 24 market periods with cash payments in the experiment (period 1 is a practice period). There will be four buyers and four sellers in the market.

### *SPECIFIC INSTRUCTIONS FOR BUYERS*

During each market period, you will have the opportunity to buy up to four units of the commodity. The first unit that you may buy in a period is worth the resale value listed in row (1) of your Record Sheet, labeled "Resale Value." The second unit you may buy in the same period is worth the resale value listed in row (4), and so on. Notice that the different units you buy within the same period may have different resale values, and these resale values may change between periods. [You can think of the resale value as the amount you can resell the commodity back to me if you are able to purchase a unit.] The profit you earn for each unit purchased is the difference between the unit's resale value and the price you pay:

$$\begin{array}{r} \text{Unit's Resale Value} \\ - \text{Purchase Price} \\ \hline = \text{Your Profit on that Unit} \end{array}$$

Therefore, you earn positive profits by purchasing units at a prices below your units' resale values. Notice that if your purchase price is greater than the unit's resale value, you will earn negative profits (losses) on that unit. If, on the other hand, you don't get purchase all four units (which may happen quite frequently), then you will receive zero profit for the units not purchased.

For example, consider the example period 0B on your Record Sheet. For this example, everyone has resale values of \$2.00, \$1.50, \$1.00 and \$0.50 for the four units. Now suppose that you buy two units in period 0B—one at a price of \$1.45 and another at a price of \$1.40. To record these purchases on your Record Sheet, enter one price paid (\$1.45) in row (2) of your Record Sheet, labeled “Price Paid,” and enter the other price paid (\$1.40) in row (5) of your Record Sheet. Do this now. [It doesn’t matter which price you enter first, as long as you enter both prices in rows (2) and (5) and *not* in the lower units’ rows (8) and (11).] You calculate profits separately for each unit by subtracting the unit’s purchase price from the unit’s resale value. Therefore, you enter  $\$2.00 - \$1.45 = \$0.55$  in row (3), labeled “Profit on Unit,” and enter  $\$1.50 - \$1.40 = \$0.10$  in row (6). Do this now. Because you do not purchase a third or fourth unit in this example, you earn profits of zero on these units, so enter 0 for the profit rows (9) and (12). Total profits for the period are the sum of the profits earned on each unit, and this total is written in row (13). For this example, the total profits for the period are  $\$0.55 + \$0.10 + \$0 + \$0 = \$0.65$ .

Your resale values are your PRIVATE INFORMATION and may be different from those of other buyers; do not let the other buyers or sellers see your Record Sheet.

### ***SPECIFIC INSTRUCTIONS FOR SELLERS***

During each market period, you will have the opportunity to sell up to four units of the commodity. The first unit that you may sell in a period costs the amount listed in row (2) of your Record Sheet, labeled “Cost of Unit.” The second unit you may sell in the same period costs the amount listed in row (5), and so on. Notice that the different units you sell within the same period may have different costs, and these costs may change between periods. [You can think of the cost value as the amount you pay to purchase the commodity from me that you subsequently sell to the buyers.] The profit you earn for each unit sold is the difference between the price you receive and the unit’s cost:

$$\begin{array}{r} \text{Price Received} \\ - \quad \text{Unit's Cost} \\ \hline = \quad \text{Your Profit on that Unit} \end{array}$$

Therefore, you earn positive profits by selling units at a prices above your units’ costs. Notice that if the price you receive is less than the unit’s cost, you will earn negative profits (losses) on that unit. If, on the other hand, you don’t get to sell all four units (which may happen quite frequently), then you will receive zero profit for the units not sold. NOTICE THAT YOU DO NOT INCUR THE COST OF A UNIT UNLESS YOU SELL THAT UNIT.

For example, consider the example period 0S on your Record Sheet. For this example, everyone has costs of \$6.00, \$6.50, \$7.00 and \$7.50 for the four units. Now suppose that you sell three units in period 0S—one at a price of \$7.35 and two at a price of \$7.10. To record these purchases on your Record Sheet, enter one price received (\$7.35) in row (1) of your Record

Sheet, labeled “Price Received,” enter another price received (\$7.10) in row (4), and enter the other price received (also \$7.10) in row (7). Do this now. [It doesn’t matter which price you enter first, as long as you enter the prices in rows (1), (4) and (7) and *not* in the fourth unit’s row (10).] You calculate profits separately for each unit by subtracting the unit’s cost from the unit’s price received. Therefore, you enter  $\$7.35 - \$6.00 = \$1.35$  in row (3), labeled “Profit on Unit,” enter  $\$7.10 - \$6.50 = \$0.60$  in row (6), and enter  $\$7.10 - \$7.00 = \$0.10$  in row (9). Do this now. Because you do not sell a fourth unit in this example, you earn profits of zero on this last unit, so enter 0 for the profit row (12). Total profits for the period are the sum of the profits earned on each unit, and this total is written in row (13). For this example, the total profits for the period are  $\$1.35 + \$0.60 + \$0.10 + \$0 = \$2.05$ .

Your costs are your PRIVATE INFORMATION and may be different from those of other sellers; do not let the other buyers or sellers see your Record Sheet.

### **HOW THE MARKET WORKS**

We now describe how the prices are determined and who gets to make purchases and sales. During each period, each buyer will submit BIDS that indicate his maximum willingness to pay for units of the commodity. At the same time, each seller will submit ASKS that indicate her minimum price that she is willing to accept in exchange for units of the commodity. As we shall explain in a moment, the buyers that trade in a period pay the amount they bid. Sellers that trade in a period receive the amount bid by a specific buyer, and they can never receive a price that is less than the amount they ask. Each buyer and each seller can trade up to 4 units each period, so each period buyers and sellers may enter bids and asks for up to 4 units.

When all the bids and asks have been submitted, they will be put separately into lists. [In this list, a bid for, say, two units will be converted into two bids, each for one unit; similarly, an ask for three units will be converted into three asks, each for one unit.] The bids will be sorted and listed from highest to lowest. The asks will be sorted and listed from lowest to highest. Any ties will be broken randomly. The lists will be put next to each other and “matched” like this:

<u>The Bids</u>		<u>The Asks</u>	<u>Price</u>
4.60	matched with	1.40	4.60
3.75	matched with	2.81	3.75
2.25	matched with	4.00	None
1.50	matched with	4.25	None

The list of bids on the left decreases from top to bottom with the highest bid on top, and the list of asks in the middle increases from top to bottom with the lowest ask on top. Notice that the bids exceed the asks for the first few pairs, and asks exceed the bids thereafter. At some point in the list there is a “crossover point” where the sorted asks start to exceed the sorted bids (after the first two units in this example). In general, all the buyers and sellers ABOVE the crossover point

will get to trade. The buyers and sellers below will not.

The buyers and sellers that trade are likely to trade at different prices in this market. BUYERS ALWAYS PAY THE AMOUNT THEY BID FOR A UNIT; SELLERS RECEIVE THE AMOUNT BID BY THE MATCHED BUYER NEXT TO THEM ON THE SORTED BID AND ASK LIST. For the example above, the buyer bidding \$4.60 pays \$4.60 to purchase a unit. The seller asking the lowest (\$1.40) receives this highest bid of \$4.60. The next buyer bidding \$3.75 pays \$3.75 to purchase a unit. The seller asking the second-lowest (\$2.81) receives this bid of \$3.75. Notice that these prices are written on the right side of this table. The bids and asks matched below the crossover point do not trade, so the buyers and sellers holding these bids and asks receive zero profit for these units this period.

Since buyers that trade always pay the amount they bid, buyers have complete control over the price they will pay for each unit. In contrast, sellers will typically not receive the amount they ask; instead, if they trade sellers will receive the amount bid by a specific buyer, NOT THEIR ASK. Notice that the sellers submitting the lowest asks receive the highest bid prices and are most likely to trade. Also note that the bid price received must always be GREATER than the amount of a seller's ask, because if an ask is matched with a lower bid then the match must be below the crossover point. To illustrate, consider this slightly different example of bids and asks:

The Bids		The Asks	Price	
4.60	matched with	1.40	4.60	the "Crossover point"
3.75	matched with	3.85	None	
2.25	matched with	4.00	None	
1.50	matched with	4.25	None	

The only difference between this example and the previous one is that the second ask (just below the crossover point) has been increased from \$2.81 to \$3.85. The second-lowest ask (\$3.85) is now greater than the second-highest bid (\$3.75), so the second unit is below the crossover point and does not trade. Because matched units below the crossover point do not trade, sellers can be assured of receiving bid prices (if they trade) that are greater than or equal to their asks.

### ***SPECIAL CASES AND EXCEPTIONS***

There are some possibilities not covered by the discussion above.

1. If all of the bids are greater than all of the asks, then everyone gets to trade. The seller with the lowest ask receives the highest bid, and the seller with the highest ask receives the lowest bid.
2. If all of the bids are less than all of the asks, then no one gets to trade and everyone earns zero profit for the period.
3. In cases where several bids or several asks are tied, the ranking of the tied bids or asks is determined randomly. For example, consider the following set of bids and asks:

<u>The Bids</u>	<u>The Asks</u>	<u>Price</u>
4.60 matched with	1.40	4.60
<u>3.75 matched with</u>	<u>2.81</u>	<u>3.75</u> the "Crossover point"
2.25 matched with	2.81	None
1.50 matched with	4.25	None

For this example, the bids exceed the asks for the top two units. Because only two units are traded, only one of the two sellers with asks of \$2.81 get to trade. The ranking of asks and the seller that trades among these two tied sellers is determined randomly. Similarly, if two buyers' bids are tied, the bid that goes higher on the list is determined randomly.

### ***HOW TO MAKE BIDS AND ASKS***

The experiment will be conducted via computer. You will submit your bids or asks through the computer, and at the end of each period the computer will report the market results. We shall now conduct the example period 1 as I teach you how to submit bids and asks. Begin by entering a bid or ask for 2 units, based on your resale values or costs of period 1. Look at your resale values or costs now.

1. If you are a buyer, you can submit bids for up to four units (your trading capacity). You enter bids in the left portion of your screen, and they will appear in blue. The arrow keys on your keyboard can be used to move around in this box. The number you enter in the column labeled BID is the price you wish to bid IN CENTS and should be prepared to pay for the unit. You indicate the number of units you are willing to purchase at this price in the column labeled Qty. Prepare a BID/Qty pair now. After you are happy with this bid price and quantity, press the function key F10 WHILE THE FLASHING CURSOR IS ON THE SAME LINE AS THE BID to send this bid to the central computer. Before your computer sends the bid, it will ask you "Are you sure?". At this point, you should double-check the bid price and quantity you are about to submit, and enter Y to confirm the submission. You should then verify that your bid was received by the central computer; you can tell it was received because it is assigned a Seq# (sequence number) which, along with your ID number, is displayed in white next to your submitted bid. [The Seq# does not mean anything; it is just used for the computers' record-keeping.]

2. Sellers submit asks in much the same way. Each seller may submit asks for up to four units (their trading capacity) each period. You enter asks in the right portion of your screen, and they will appear in green. The number you enter in the column labeled ASK is the minimum price you would be willing to accept IN CENTS. You indicate the number of units you are willing to sell at this price in the column labeled Qty. After you are happy with this ask price and quantity, press the function key F10 WHILE THE FLASHING CURSOR IS ON THE SAME LINE AS THE ASK to send this bid to the central computer. Before you type Y to confirm the ask submission you should double-check the ask price and quantity you are about to submit. You

should then verify that your ask was received by the central computer; you can tell it was received because it is assigned a Seq# (sequence number) which, along with your ID number, is displayed in white next to your submitted ask.

3. Buyers and sellers can submit multiple bids or asks in each period, as long as the total number of units associated with those bids or asks does not exceed four. For example, you could enter four one-unit bids, one four-unit bid, or other combinations. If you wish to submit another bid or ask, enter the new bid or ask price and quantity on A DIFFERENT line in your box. WHILE THE FLASHING CURSOR IS ON THE SAME LINE AS THE NEW BID OR ASK YOU WISH TO SUBMIT, you must press F10 again to send this bid or ask to the central computer. Remember to verify that the bid or ask was received by noting that a Seq# has appeared next to it in white. Try submitting another practice bid or ask for one or two units now.

4. Following each period, I will close the period and the computer will report back to you all the bids and asks and the trading prices. Watch as I do this now. You can identify your bids or asks on this list with \*'s or square's. If you had a bid or an ask for a multiple quantity of units such as two, notice that the central computer has converted this to two single-unit bids. It does this for the purpose of matching units with the other side of the market. The bids on the left are sorted so they decrease from top to bottom, and the highest bid is on top. The asks in the middle are sorted so they increase from top to bottom and the lowest ask is on the top of your screen. The PRICE column on the right indicates the transaction price for all the bid-ask matches above the crossover point. Notice that these prices are equal to the bid for each match. The bids or asks submitted BY YOU that result in transactions are indicated on this list with \*'s. In addition to the \*, for the units you trade the price you pay or receive is indicated in the far-right column labeled Amount. This is the "Price Paid" or "Price Received" that you enter on your Record Sheet; enter these on your Record Sheet now, and remember to enter the price for the first unit traded in the top blank of your record sheet for period 1, etc. The bids or asks submitted by you that do not result in a transaction (that is, are below the crossover point) are indicated with white square's. Calculate your profits for this period as instructed earlier, and enter the total profit (which is not paid in this practice period) in row (13). I will come around now to check your calculations.

5. If the list of bids and asks is very long, you can use the ↑ and ↓ arrow keys or the PgUp and PgDn keys to scroll through the list. In later periods you can view previous period outcomes during the experiment by HOLDING DOWN THE CNTL KEY while pressing PgUp.

### **SUMMARY**

- |    |   |                                |
|----|---|--------------------------------|
| 1. | Buyer's profit = (resale value) - (price paid)    | for each unit you trade,       |
|    | Buyer's profit = 0                                | for each unit you don't trade. |
| 2. | Seller's profit = (price received) - (cost value) | for each unit you trade,       |
|    | Seller's profit = 0                               | for each unit you don't trade. |



3. Each buyer may buy up to 4 units and each seller may sell up to 4 units each period.
4. The *crossover point* on the sorted bid and ask lists is where asks begin to exceed the bids.
5. Traders above the crossover point will get to trade, and the price is determined by the buyers' bids. Buyers that trade pay the amount they bid.
6. Sellers' asks determine their ranking on the bid/ask match. Sellers that trade receive the amount bid by the buyer with whom they are matched.
7. You start with a cash balance of \$5.00. Your profits will be added to this balance, and your losses (if any) will be subtracted from this balance (you keep track of this balance in the Current Balance row (14) of your record sheet).
8. Please do not talk to any other participant or reveal any of your information (including your costs or resale values) during the experiment. If you ever have a question, please raise your hand and I will be happy to answer it.

We are about to begin period 2 for real money. Are there any questions now?